1999
INVESTIGATORS' ANNUAL REPORTS

YELLOWSTONE NATIONAL PARK

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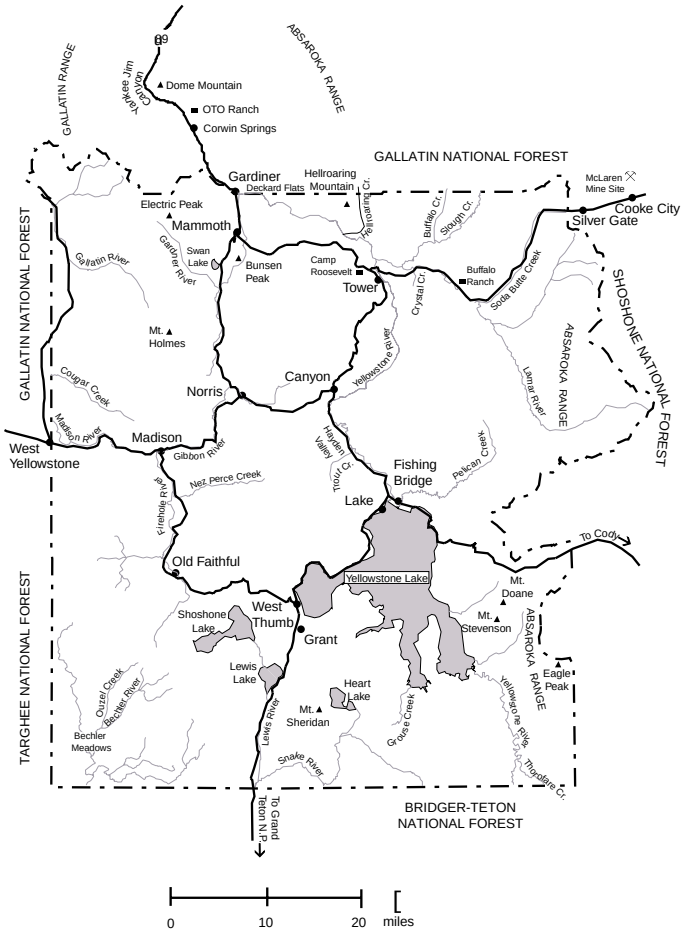

Yellowstone Center for Resources
P.O. Box 168
Yellowstone National Park, Wyoming 82190

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Cover: In 1999, scientists found the last remnants of this whitebark pine that grew centuries ago above modern timberline. Tree rings in this piece of ancient wood and others like it provide information about regional climate changes over the last 1,000 years. Remnants from several species of trees are preserved in Yellowstone's highlands, allowing scientists to analyze both moisture and temperature patterns during prehistoric times.

Acknowledgments: The National Park Service thanks the researchers that have contributed vastly to our understanding and knowledge of this special place.

FOREWORD

Science permeates nearly every aspect of Yellowstone management. Wildlife managers require answers to questions like how many grizzly bears exist in the Greater Yellowstone Area and what can be done to make the park safer for both bears and visitors? How does brucellosis in bison and elk differ from that in domestic cattle? Why has trumpeter swan reproduction declined? Historical research and archeological studies help us better understand the stories behind American Indian artifacts and historic buildings. Decisions on the best techniques for preserving these priceless objects also result from scientific inquiry. The social sciences help park managers develop better strategies for visitor use management by assessing public opinion, visitor satisfaction, and social carrying capacities.

As one of the few landscapes remaining in the continental U.S. with all of its original wild components functioning with minimal human interference, Yellowstone provides superb opportunities for close study of a naturally functioning ecosystem. Nonetheless, Yellowstone lacks the funds to do all of the needed research itself, and is dependent to a large extent on research done by scientists from other government agencies, academic institutions, and the private sector. The results of this research are important to non-park areas as well as to the park itself, because Yellowstone provides an ecological baseline from which the effects and influences of humans on the landscape can be assessed and compared.

In 1999, 256 research projects were approved; 71 were new, and 185 were continued from previous years. About 30 percent of all hypothesis-driven research in Yellowstone attempted to answer questions related to the park's wildlife. Nearly 20 percent of hypothesis-driven research related to microorganisms, and another 20 percent was dedicated to geology. Studies of the park's aquatic systems and plant populations each accounted for another 10 percent of research projects. The remaining projects included important endeavors such as archeological surveys, air quality studies, fire conditions monitoring, and paleontology. In addition, 10 percent of all research permits were not driven by the search to prove or disprove a hypothesis. These permits supported the education of future scientists by allowing students and their teachers to conduct simple scientific studies in the park.

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AIR QUALITY

Project title:	**Characterization of Snowmobile Particulate Emissions**
Principal investigator:	Jeff White
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Additional investigators:	Jim Carroll

Objective: Snowmobile engine emissions are of concern in environmentally sensitive areas, such as Yellowstone National Park. Previous studies have investigated snowmobile engine gaseous emissions, including HC, CO, NOx, and CO_2, as well as, polycyclic aromatic hydrocarbons (PAHs). This project extended this previous research by investigating the character of snowmobile engine particulate matter (PM) emissions. Two issues were investigated. First, additional information was obtained about the chemical composition of the PM. Second, the size distribution of the PM was investigated to determine whether the particles are of respirable size. This information will help to better answer questions about potential health effects of snowmobile PM.

Findings: Gaseous emission rates from this 488 cc two-stroke Polaris engine (manufactured by Fuji Heavy Industries) agreed well with data generated on a same-model engine in a recently completed study for the Montana Department of Environmental Quality. This work confirmed that two-stroke snowmobile PM emissions are composed primarily of volatile organics, which are principally lubricant derived. Particle diameters were found to be typically less than 100 nanometers, which is of respirable size and able to be delivered into the lung. Bioassay results showed that snowmobile PM is mutagenic, at a level similar to that of PM from diesel engines.

ARCHEOLOGY

Project title:	**Geochemical Investigations of Obsidian Source Material**
Principal investigator:	Kenneth Cannon
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Additional investigators:	Richard Hughes

Objective: To collect provenience and geochemical data on geologic sources of toolstone quality obsidian. This database will be used to compare geochemical data of artifacts for discerning aboriginal use of obsidian sources. This information will be useful in determining patterns of lithic procurement and land use in the Greater Yellowstone Ecosystem and beyond

.

Findings:No fieldwork was conducted in YNP during 1999. However, we did conduct collections on private and Forest Service lands in Jackson Hole. This work provides us with a better understanding of two geochemical types in the Teton Pass area.

Project title:	**Miscellaneous Archeological Research in Yellowstone National Park**
Principal investigator:	Dr. Leslie Davis
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Address:	Museum of the Rockies Montana State University Bozeman, MT 59717-0272
Additional investigators:	Brian Reeves

Objective: Fieldwork in 1999 was a combination of research- and compliance-directed inventory and evaluations. The archeological research completed inventory of the Yellowstone River corridor from Fishing Bridge north to the river exit from the park (approximately 100 miles of bank), which was begun in 1997. As part of this work, one site was tested in the Black Canyon of the Yellowstone, revealing a Late Prehistoric camp overlying a Pelican Lake (~2,000 years old) campsite.

Compliance-driven fieldwork included work for the Federal Highway Administration: testing of site 24YE89 on the Mammoth-Gardiner road section, inventory of the highway right-of-way between Madison Junction and West Yellowstone; inventory for the Reese Creek prescribed burn, Bannock Trail inventory, trail reroutes, and inventory for the proposed bison corral at Seven Mile Bridge (and testing of site 48YE644).

Findings: There were 2,847 intensively inventoried acres, with 97 new sites and 15 isolated finds recorded and two sites tested. We are working on research questions regarding cultural chronology (who was here in the past), seasonality, and subsistence. A particular focus has been lithic resource management with sourcing using x-ray fluorescence of obsidian and rhyodacite artifacts. We have begun to source as many specimens as possible from sites, and one site this summer had obsidian artifacts manufactured from five different obsidians. A future step will be to study obsidian source patterning in different parts of the park to see what this will tell us about seasonal movements, source availability, and cultural preferences through time. We have compiled a list of 55 archeological radiocarbon dates for the park. All collected artifacts are being catalogued. These reports were completed and are on file at the Yellowstone Center for Resources.

Project title:	**Miscellaneous Archaeological Investigators in Yellowstone National Park**
Principal investigator:	David Eckles
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Additional investigators:	Paul H. Sanders

Objective: Miscellaneous archaeological investigations in Yellowstone National Park, including test excavations at sites 24YE14, 48YE867, and 12 sites along the Canyon to Lake Junction road, and a Class III cultural resource inventory of the Otter Creek bear-feeding station.

Findings: The investigation at site 24YE14 revealed stratified natural and cultural deposits within an ephemeral braided stream environment. Four cultural components were radiocarbon dated to 1,560-1,700, 2,350-2,380, 2,510-2,570, and 5,200. Cultural materials included hearth features, faunal remains, and chipped stone tools and debitage from temporary campsite activities. The testing at site 48YE867 consisted of a rough grid system of 75 shovel tests, two of which yielded cultural materials. The 12 sites along the Canyon to Lake road were all prehistoric lithic scatters that varied in size and complexity. Two sites contained buried Paleoindian artifacts, some of the first in Yellowstone. The Class III cultural resource inventory resulted in the recording of the Otter Creek Bear-feeding station, a 1930-1940s tourist attraction.

Project title:	**Chemical Analysis of Obsidian Sources and Artifacts from the Northwest and Great Plains USA**
Principal investigator:	Dr. Michael D. Glascock
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Address:	Research Reactor Center University of Missouri Columbia, MO 65211
Additional investigators:	Craig E. Skinner

Objective: The major objective of this research is to establish a geochemical database of obsidian sources in the northwestern USA, including sources in the Yellowstone National Park and adjoining areas. Samples of obsidian from various source areas are collected and analyzed by two analytical techniques (neutron activation analysis and x-ray fluorescence analysis) to establish the database. In addition, the source samples are being collected from primary outcrops and secondary deposits to establish the true availability of each obsidian source group to prehistoric peoples. The geographic coordinates of each sample are being entered into the database along with the chemical analysis information. Artifacts will be analyzed similarly and compared to the source database.

Findings: During the fall of 1999, obsidian artifacts from sites in Wyoming and South Dakota were analyzed and compared to the source database for in Yellowstone National Park and the surrounding region. Although the Obsidian Cliff source in Yellowstone National Park was dominant amongst the artifacts, the results were interesting in terms of the distributions and distance from other sources represented. Sources from Idaho and Utah were found in significant numbers to indicate a greater distance of travel than one might have originally anticipated. This research has benefited from the detailed collection and sample analysis undertaken by NAA and XRF in our laboratories.

Project title:	**Obsidian Studies: XRF Characterization of Obsidian Sources of Yellowstone National Park**
Principal investigator:	Dr. Raymond Kunselman
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Objective: Characterizing obsidian sources for chemical composition using XRF to be able to match prehistoric artifacts to their obsidian source. Yellowstone obsidian has ended up in prehistoric sites in Iowa, Colorado, Wyoming, and several other states, and is useful to study trade and interactions.

Findings: The main Yellowstone source was Obsidian Cliff, and prehistoric obsidian artifacts ended up in many states. The amount that was procured directly and the amount traded down-the-line has not been determined, and this determination of kinds of contact is an active research area.

BOTANY

Project title:	***Cortinarius* in Yellowstone**
Principal investigator:	Joe Ammirati
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Additional investigators:	Michelle Seidl, Brandon Matheny, Brad Kropp, Meinhard Moser

Objective: Taxonomic studies in the genus *Cortinarius* and related genera, including general ecology, phenology, geography, and photography and painting of specimens.

Findings: 1999 was one of the poorest collecting seasons in the past fifteen years, therefore, success was limited. Collection made by investigators are recorded by genus below followed by a number indicating the total number of collections. *Cortinarius*, 7; *Inocybe*, 16; *Clitocybe,* 2; *Peziza*, 1; *Mycena*, 2; *Lactarius*, 2; *Galerina*, 3; *Russula*, 2; *Laccaria*, 1.

Project title:	**Parkwide Seedbank**
Principal investigator:	Eleanor Clark
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Additional investigators:	Sam Reid, Cheryl Decker, Stephanie Cochrane, Orvin Loterbauer

Objective: Collect and catalogue native seed to be used for parkwide roadway disturbance.

Findings: Seed collection continues to accumulate an adequate amount for revegetation of roadway and construction disturbance.

Project title:	**Lichens of Yellowstone National Park: Phase II**
Principal investigator:	Dr. Sharon Eversman
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Email:	*eversman@montana.edu*
Address:	Biology Department Montana State University Bozeman, MT 59717
Additional investigators:	Clifford Wetmore, Katherine Glew, James Bennett

Objective: The objectives were to: 1) Further the completion of an inventory of lichens of Yellowstone National Park; and 2) Collect two species, *Bryoria fremontii* and *Letharia vulpina*, for element analysis of their tissues.

Findings: Three hundred sixty-four lichens species in 105 genera have now been identified from 84 sites in Yellowstone National Park; 190 species were reported from the park for the first time. Douglas fir bark burned in 1988 is being re-colonized by eight species, and burned soil in a Douglas fir forest zone is being re-colonized by two species.

Forty-three species have been reported as being sensitive or intermediately sensitive to air pollutants. *Bryoria fremontii* and *Letharia vulpina* tissues analyzed for elemental content show that, except for mercury, the levels of most elements were similar to those recorded in other parts of the region. The final report, Lichens of Yellowstone National Park, Phase II, has been completed and printed. A copy was sent to YNP.

Project title:	**Vascular Flora of the Greater Yellowstone Area**
Principal investigator:	Erwin Evert
Phone number:	847-823-1501
Address:	1476 Tyrell Park Ridge, IL 60068

Objective: To collect vascular plant specimens as vouchers for distribution maps to be included in the investigator's Flora of the Greater Yellowstone Area. For other objectives, see the investigator's research proposal outline.

Findings: Six vascular plant species previously unreported for YNP were collected: 1) *Chorispora tenella*; 2) *Ranunculus acris;* 3) *Picea glauca*; 4) *Rumex utahensis;* 5*) Myosurus minimus;* and 6) *Carex leporinella.* #1 Black Canyon, #2-4 Slough Creek drainage, #5 and 6 Pelican Creek drainage. In addition, five seldom seen species were collected: *Arenaria serpyllifolia*, *Viola canadensis*, *Carex concinna*, *Oryzopsis asperifolia*, *and Onobrychis viciifolia*.

Editor's Note: The following speices, *Chorispora tenella, Ranunculus acris, Picea glauca*, *Myosurus minimus,* and *Carex leporinella* have been previously reported for Yellowstone National Park.

Project title: **Wetland Conservation Planning**

Principal investigator: Robert Moseley
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Address: Conservation Data Center
Idaho Department of Fish and Game
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Objective: Compile a centralized wetland information system for Idaho and prepare wetland conservation plans by watersheds. The first watershed done under this project was the Henrys Fork basin, including the Idaho portion of YNP.

Findings: Inventories were conducted in the Henrys Fork basin but not in Yellowstone National Park this year.

Project title: **Remote Sensing of Aspen Change on the Northern Range of Yellowstone National Park**

Principal investigator: Dr. William Ripple
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Additional investigators: Eric J. Larsen

Objective: Historical aerial photography will be used to analyze aspen and conifer canopy cover change over a 40-year period on the northern range of Yellowstone National Park and on adjacent public lands in the Shoshone and Gallatin national forests. Aspen cores and belt transect information will also be collected to aid in the analysis. The specific objectives of the study are: 1) Using aerial photography, map changes in woody vegetation on YNP's northern range and on selected comparable plots in the Shoshone and Gallatin national forests. 2) Compare changes in aspen/conifer canopy coverage on the northern range plots with changes observed on the Shoshone and Gallatin National Forest plots. 3) Integrate field-collected transect and core data with remote sensing results to attempt to determine the

causes for any observed differences.

Findings: At the conclusion of the 1999 field season, data had been obtained from 94 randomly selected plots in YNP, 97 plots in the Shoshone National Forest, and 67 plots in the Gallatin National Forest. Preliminary analysis of the data indicates that YNP aspen stands may have a different age structure than those in the adjoining national forests, including the elk wintering areas of the Sunlight/ Crandall basins of the Shoshone National Forest. The data are being analyzed to compare age distributions, sucker densities, bark damage to boles, browsing intensity, and the degree of conifer invasion in aspen stands. Using paired sets of aerial photographs, aspen/conifer canopy cover change for the period 1954-1992 (1958-1995 in the national forests) is still in progress.

Project title: **Physiology of Thermotolerant Plants in Yellowstone Park**

Principal investigator: Dr. Richard Stout
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Objective: Our chief objectives for 1999 were to continue to monitor the rhizosphere temperatures of plants growing in several geothermal areas in Yellowstone and to begin a systematic vegetative pattern survey in these areas.

Findings: This year we collected additional data logger temperature data regarding long-term (weeks to months) rhizosphere temperatures of the grass species *D. lanuginosum*. These results were in general agreement with results from previous years; that is, that the roots of this plant are exposed to temperatures exceeding 40° C for weeks. In addition, we collected vegetative pattern data in selected areas at Amphitheater Springs, 100 Springs Plain, and Rabbit Creek. At this time the data is inconclusive regarding correlations between physical factors and species distribution in geothermal areas. We plan to continue this research next year.

Project title: **Yellowstone Flora**

Principal investigator: Jennifer Whipple
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Objective: The vascular plant flora of Yellowstone, even though investigated for approximately 120 years, is not completely known. The primary focus of this project is to improve the current knowledge of the flora of the park through in-depth collecting, especially park areas which have not been previously studied. This includes inventory of the occurrence and range of native taxa and also involves the documentation of the arrival and spread of exotic species. In addition, collection of specimens for the Yellowstone herbarium will improve the value of the facility for both NPS personnel and outside researchers.

Findings: Ongoing inventory of vascular plants and collection for the Yellowstone National Park Herbarium (YELLO). Seven species of vascular plants previously not reported as occurring within the park were discovered. *Cymopterus nivalis* Wats. (snowline cymopterus), *Thlaspi montanum* L. (wild candytuft), *Mirabilis linearis (*Pursh) Heimerl (narrowleaved four-o'clock), *Orobanche corymbosa* (flat-topped brooomrape), and *Carex nigricans* Retz. (black alpine sedge) were all located apparently for the first time in the park. These native species are presumed to have been a long-term component of Yellowstone's flora that had been previously overlooked. Additionally, two new exotic species were discovered and subsequently eradicated. *Daucus carota* L. (Queen Anne's lace) was located by West District resource management personnel, and *Arctium minus* (Hill) Bernh. (burdock) was discovered in the lawn of a residence in lower Mammoth. In addition, *Listera convallarioides* (Sw.) Nutt. (broad-lipped twayblade), originally collected in 1885 but subsequently not relocated, was confirmed to occur within the park.

CLIMATOLOGY

Project title:	**Temperature Variability in the Western U.S. since AD 1000 from Tree Rings**
Principal investigator:	Peter Brown
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Additional investigators:	Malcolm Hughes, Connie Woodhouse

Objective: Collect high-elevation old-age trees in Yellowstone NP for reconstruction of temperature patterns over the past millennium. This study is funded by NSF to develop chronologies over the northern Rockies and Cascades.

Findings: Collections at Craig and Sylvan Passes did not find trees of sufficient ages for the purposes of our study. Cores collected in these spots will be archived with others collected as part of the larger study.

Project title:	**Snow Pack on Northern Range**
Principal investigator:	Phillip Farnes
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Address:	P.O. Box 691 Bozeman, MT 59771-0691

Objective: Compare snow variation with plant and animal responses.

Findings: Plants, animals, and fish respond to weather conditions more than they do to time periods and responses are predictable.

ECOLOGY

Project title:	**The Ecological Relationship Between a Rocky Mountain Threatened Species and a Great Plains Agricultural Pest**
Principal investigator:	Dr. Peter F. Brussard
Phone number:	775-784-1360
Email:	*brussard@biodiversity.unr.edu*
Address:	University of Nevada, Reno Biology Department 314 Reno, NV 89557
Additional investigators:	Hillary Lindsay-Robison

Objective: 1) To determine where army cutworm moths (*Euxoa auxiliaris*) (ACMs) originate. Pressures on ACM subpopulations, either natural (e.g., weather patterns) or human-caused (e.g., pesticides), may affect moth recruitment and the number of adults reaching high elevation sites where they are a critical food source for the threatened grizzly bear (*Ursus arctos horribilis*). 2) To determine if ACMs harbor agricultural pesticide residues in their tissues. Resulting pesticide magnification in grizzly bears that forage heavily on moths may have detrimental physiological or developmental side effects. 3) To elucidate the effects of weather on ACM migration from Great Plains agricultural areas to ACM aggregation sites in the Rocky Mountains. 4) To determine whether ACMs from different Great Plains origins are interbreeding in high elevation sites prior to their return to agricultural areas. If ACM subpopulations do not interbreed, unfavorable conditions in specific Great Plains areas may impact moth numbers in high elevation.

Findings: After completion of field work, data will analyzed, written in a Ph.D. thesis, and manuscript(s) submitted to peer-reviewed journals in 2002.

Project title: **Carnivore Detection Survey**

Principal investigator: Dr. Robert Crabtree
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Additional investigators: M. Miller, D. Bopp

Objective: 1) Assess several methods to inventory and monitor medium-sized carnivores: weasel, otter, wolverine, marten, fisher, lynx, bobcat, mountain lion, fox, coyote, and gray wolf. 2) Examine various habitat and landscape characteristics related to their presence/absence. 3) Conduct presence/absence surveys in Yellowstone National Park and surrounding wilderness areas.

Findings: With the notable exception of three decades of research on grizzly bears, and more recent studies on mountain lions, pine marten, and coyotes, we know very little about Yellowstone's mammalian carnivores. Members of the order *Carnivora* are typically secretive, nocturnal, and exist at low population densities. In many cases, we do not even have reliable methods to determine presence, let alone estimates of abundance and other important demographic parameters. During the winters of 1990 through 1997 we conducted detection surveys and evaluated three methods: hair snares, remote camera stations, and snow track transects. Their utility as estimates of presence, distribution, and abundance were evaluated, as well as their cost, maintenance, reliability, precision, and bias. Responses to hair snares and camera stations were variable locally and between years. Hair snares have the exceptional advantage of providing DNA and potentially identifying individuals, but have the disadvantage of relatively high maintenance and cost, and they provided unreliable results from the analysis of hair characteristics. Camera stations, like hair snares, performed well in adverse weather and can identify individuals, but suffer from avoidance bias by several resident species. Camera stations were costly in terms of expense and maintenance. Snow track transects identified four species not detected by other methods and were simple, low cost, and low maintenance. They provide precise habitat information, whereas camera stations and hair snares are baited with food and scent lures, which bias results concerning habitat use. Snow track transects allow researchers coverage of large areas and habitat types and can provide valuable information if scats are found and if DNA is successfully extracted. The reliability of species identification from snow track transects is a major disadvantage due to poor climatic conditions and the similarity of many species' track characteristics. Although the specifics of objectives and logistics should dictate use of these methods, we suggest a variable combination of all three methods for determining presence and distribution. All methods have significant problems, especially when inferring abundance. Determining relative habitat use from snow track transects proved reliable and matched that known from previous studies. A manuscript was prepared on the evaluation of these three detection methods for medium-sized carnivores.

Project title:	**Landscape Use by Elk During Winter on Yellowstone's Northern Range**
Principal investigator:	Dr. Robert Crabtree
Phone number:	See previous entry
Additional investigators:	P. Moorcroft, Kirk Johnson, Phil Farnes, Mark Lewis

Objective: The objectives of this study were to document winter patterns of landscape use by Yellowstone northern range elk, measure elk feeding activity (as indexed by number of feeding craters), quantify snowpack characteristics, and examine how these and other landscape and habitat features influence elk foraging locations. How does snow affect the distibution of elk during winter on Yellowstone's Northern Range? What other factors, such as winter temperature, forage, and predator/prey density, are affecting their distribution?

Findings: We measured site and snowpack characteristics, elk (*Cervus elaphus*) feeding crater densities and morphometry, and elk numbers in the Lamar River valley and the Blacktail Plateau on the northern range of Yellowstone National Park. We conducted the study over three winters, 1992-93 to 1994-95, but the main sampling effort occurred over four monthly sample periods in year one. Snow depth, snow water equivalent (SWE) and snow resistance to horizontal movement and vertical penetration all increased steadily over the winter. The mean (SD) feeding crater diameter and depth was 118 (37) cm and 34 (11) cm, respectively, and both were positively correlated with snow depth. The mean (SD) crater volume was 385 (321) liters, and the mean (SD) mass of snow excavated from a crater was 82 (72) kg. Non-woody plants (grasses, sedges and forbs) were the primary browse item in 90% of the craters. The highest aerial elk counts were observed in early- to mid-January, and counts declined substantially and steadily after January 29. At this time, mean snow depth was about 50 cm and mean SWE was about 12 cm. The mean number of new craters on a plot showed a significant, negative association with snow depth, SWE, and booted-foot sinking depth. We used the sum of craters on a plot across all four sample periods as an index of winter-long feeding activity. Elevation and habitat type were the best site characteristics for differentiating plots in regard to winter-long use. Summed craters were negatively associated with elevation, and the habitat type with the highest summed craters was tufted hairgrass/sedge. Only about 5% of plots that had craters had aerial crater coverage in excess of 14%, with a maximum of 23% coverage, suggesting that snow disturbance associated with cratering activity may inhibit elk foraging.

Project title: **Ecology and Distribution of Red Fox (*Vulpes vulpes*) in Northern Yellowstone**

Principal investigator: Dr. Robert Crabtree
Phone number: See previous entry

Additional investigators: Robert Fuhrmann, Brad Swanson

Objective: 1) Determine habitat use of northern Yellowstone's red fox. 2) Examine the genetic variability of red fox subpopulations according to three elevational zones.

Findings: The distribution, morphology, and habitat use of red fox was examined in the northern Yellowstone ecosystem. Morphological and genetic samples were collected on live-captured and dead foxes to identify the presence and distribution of potential red fox subspecies across an elevational gradient. Examination of 22 red foxes indicated shorter tail length above 7,200 feet. Other parameters indicated trends of beneficial adaptations to climatically harsh environments at high elevations. At elevations above 7,200 feet, there was significantly higher frequency of a light gray coat color morph. Genetic analysis indicated that foxes above 7,200 feet were genetically isolated from lower elevations yet no geographic barrier exists. Habitat use was evaluated by snow-tracking fox using GPS and GIS technologies. Foxes were distributed across the study area in a wide range of forest cover types. Results show that red fox prefer forested and forest-edge habitats. Foxes significantly selected habitats that were less than 25 meters from an ecotone (structural edge). They preferred mesic sedge meadows and spruce-fir habitats at low angle slopes with a wide range in aspect. Lower elevational populations on the northern range were less specific in their selection of habitats and foraged mostly in mesic meadows and sagebrush. Above 7,200 feet, foxes preferred spruce-fir forests and foraged in mesic meadows and in spruce-fir and old-aged lodgepole forests. Clearly the mountain red fox that inhabits northern Yellowstone should be classified as a forest carnivore and is quite possibly a new subspecies of mountain fox, indigenous to North America. Further analysis and preparation of manuscripts will occur in 2000.

Project title: **Effects of 1988 Fires on Ecology of Coyotes in Yellowstone National Park: Baseline Succeeding Wolf Recovery**

Principal investigator: Dr. Robert Crabtree
Phone number: See previous entry

Additional investigators: J. Sheldon, C. Wilmers, A. Switalski, D. Bopp

Objective: Document long-term effects of the 1988 fires on the population dynamics and behavioral ecology of coyotes. Document the impacts of wolf restoration on coyote population and behavioral ecology, including the effects on coyote prey and competitor species. Continue long-term monitoring of coyote populations by adherence to those objectives listed in previous reports and peer-reviewed publi-

cations.

Findings: This project is beginning year 11 and is in the phase II: wolf-colonization period. A variety of significant behavioral and demographic effects of wolves on coyotes have occurred since the release of wolves in 1995. The effect of fires on coyotes directly continues to be insignificant, however indirect effects on the small-mammal prey base community continue. Forty-five resident adult coyotes occupy the Lamar Valley study area. This continues a well-established trend of an approximate 50% reduction compared to pre-wolf numbers. Almost complete extirpation of coyotes exists in the core area of the Druid wolf pack. Neonatal pup survival remains high (70 to 80%) but fall mortality (mostly due to wolves) was the highest ever recorded since the beginning of the study. We observed wolves killing coyotes in nine instances this year. Wolves raided coyote dens in at least eight instances. The first documentation of wolves killing and consuming a coyote pup occurred this year. Other behavioral impacts are still occurring: relegation of coyote dens to low wolf-use areas, high turnover of alpha pairs due to mortality, shifting territoriality, and low pack size. A functional increase in coyote scavenging (and other scavengers: eagles, ravens, bears) has occurred in response to the availability of wolf carcasses.

Project title:	**Yellowstone Watersheds Initiative**
Principal investigator:	Dr. Robert Crabtree
Phone number:	See previous entry
Additional investigators:	G. Terrie, J. Spruce, W. Minshall, R. Gresswell, G. Meyer, A. Marcus, J. Varley

Objective: Due to "funnel effects," streams, riparian, and wetland areas are the accumulation zones of environmental disturbances occurring throughout their watersheds. For example, they are profoundly affected by eroded sediments from disturbances such as logging operations, forest fires, mining, recreation, and grazing. These disturbances introduce significant changes in stream sediment loads, stream morphology, and riparian vegetation. Because of funnel effects, stream and riparian areas are among the most sensitive indicators of large-scale environmental change. This general research initiative allows Yellowstone Ecosystem Studies to: 1) assist Yellowstone National Park with the monitoring of fish populations, stream characteristics, watershed impacts, and riparian and wetland assessments; 2) examine the effects of fire, exotics, mining activities, and other human impacts on stream, riparian, and wetland ecology; and 3) conduct data collection and analysis and prepare manuscripts.

Findings: This general initiative was primarily involved with the collection of multi-sensor data of stream, riparian, and wetland habitats in 1999. Extensive data were collected: 1) 14 band ATLAS (including 6 thermal bands); 2) 0.7 meter 4-band (digital); 3) 12-band AIRSAR (C, L, and P bands); 4) RadarSat (C-band); and 5) double x-band IFSARE. These data sets will provide the basis for the development of a remote-sensing approach to inventory and monitoring, as well as provide the basis for

the development of indicators that reflect the ecological integrity of the associated watersheds. Streams and riparian areas have been relatively ignored by remote sensing researchers. This is primarily because the relatively low spatial and spectral resolution of traditional remote sensing data has not been conducive to successful analysis of these vital ecological lifelines. The corpus of scientific literature on remote sensing of streams is lean. Previous research suggests that finer-scale imaging with multiple sensors can achieve a major breakthrough in remote sensing of stream, riparian, and wetland areas for both scientific and commercial applications. Year 2000 efforts will focus on analysis and classification utilizing the multi-sensors listed above.

Project title:	**Validation of High Resolution Hyperspectral Data for Stream and Riparian Habitat Analysis**
Principal investigator:	Dr. Robert Crabtree
Phone number:	See previous entry
Additional investigators:	J. Boardman, A. Marcus, R. Aspinall, D. Despain, W. Minshall, K. Halligan, J. Norland, J. Richardson, L. Foss

Objective: The objectives of this hyperspectral EOCAP project are twofold. First, the project seeks to test the application of airborne hyperspectral imagery to riparian and in-stream ecological and environmental studies and monitoring. Secondly, using experience gleaned from these application tests, we are defining the unique and common requirements of hyperspectral data for operational commercial and scientific uses in the area of stream and habitat analysis. The results we are creating fall into these two broad categories: specific stream study application results and more general conclusions about commercial hyperspectral data requirements. We are documenting which specific stream ecology variables can best be measured from airborne hyperspectral sensors, and which stream parameters are not amenable to hyperspectral determination. Through acquisition of the field and airborne data, development of experimental protocols, analysis, and processing of the hyperspectral data and documentation of the results, we are building the case for stream and riparian studies using hyperspectral data. Furthermore we are discovering, often through the process of trial and error, numerous critical gaps and deficiencies that exist in current systems that hinder the commercialization of hyperspectral data for riparian studies.

Findings: In 1999 a variety of hyperspectral data sets were collected or obtained: 1 meter, 5 meter, and 10 meter Probe-1 (128 channels) and 2 meter and 17 meter AVIRIS data (224 channels). Extensive ground-truth data were collected along the Soda Butte and Cache Creek study sites. Six main classes of ecological parameters that we seek to study and classify are: 1) stream morphological units; 2) steam depth and flow regime; 3) substrate particle size; 4) in-stream algae chlorophyll levels; 5) woody debris; 6) heavy metals and associated mine tailings in fluvial sediments; and 7) riparian vegetation community mapping including individual species identification of willow, sedge, cottonwood, aspen, upland grasses, rushes, alder, sagebrush, and conifer species.

These six main classes of variables span the range from relatively easy to extremely difficult, in terms of

hyperspectral measurement. Each ecological variable has its own degree of hyperspectral "leverage", or observability in the hyperspectral data. Furthermore, key issues such as spatial and spectral resolution, noise level, geometric fidelity, geopositioning accuracy, and timeliness of data delivery and processing affect each specific application differently. Using multiple spatial and spectral resolutions, and multitemporal data sets, we are investigating and documenting the complex interplay between instrument and data parameters and the usefulness and accuracy of the derived ecological products.

While spectral contrasts exist among classes and species of vegetation, and even exist among subclasses of a single type, they are subtle and change throughout the growing season. Unlike the small spatial scale and rapidly time-varying nature of the in-stream parameters, the riparian vegetation is distributed in broader units that generally persist from one season to the next. Successful mapping of these plant species rests heavily on correlation of field spectrometry with airborne data. This particular application lends itself to a multitemporal approach, leveraging the different spectral "trajectories" of the plant communities throughout the growing season. Initial investigations of the airborne data show tremendous spectral diversity in the riparian vegetation. Empirical spectral analysis indicates that more than a dozen spectrally unique vegetation classes can be mapped. Current efforts involve matching field mapping with the aircraft data results.

Throughout our EOCAP project we are focusing on our dual hyperspectral objectives: developing convincing case study demonstrations of the hyperspectral measurement of important stream and riparian ecology parameters and documenting and developing the common and unique requirements of operational systems to perform these studies in the future. Specifically, we are collecting a laundry list of needs and requirements for commercial systems for hyperspectral stream studies. This list documents specific spatial, spectral, and radiometric design requirements. In addition, we are addressing the more mundane, yet critical, aspects of operational acquisition and application including the timely delivery of data and products and its long-term use and archiving. Our initial results from our first field season are very encouraging and productive, both in terms of the development of tantalizing case studies and the frustration involved with finding and documenting technology gaps and shortcomings.

Project title:	**Specificity of Ectomycorrhizal Symbioses**
Principal investigator:	Dr. Ken Cullings
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Additional investigators:	Sharon Cullings, J.R. Blair, Debie Kinsey, Robert Douglas

Objective: 1) To determine whether specificity exists in the ectomycorrhizal community. 2) To determine effects of disturbance and chemical gradients on ectomycorrhizal community structure and

specificity patterns.

Findings: 1) Defoliation has a significant effect on ectomycorrhizal community composition. 2) There is no significant difference in ectomycorrhizal community structure between wet and dry periods of a single growing season, but there is between winter and summer. 3) Litter addition has a significant effect on mycorrhizal root distribution and on fruiting. Analysis of changes to species composition is in progress.

Project title:	**Habitat Requirements and Evolution of *Agrostis rossiae* Vasey, a Species Endemic to Yellowstone National Park**
Principal investigator:	Dr. Steven Darwin
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Additional investigators:	Michael Tercek

Objective: *Agrostis rossiae* is a grass endemic to thermal areas in the Old Faithful-Shoshone area. Populations are small and isolated, but are usually parapatrically distributed with respect to a morphologically similar, cosmopolitan congener, *Agrostis scabra*. Both species are highly plastic and converge morphologically in some populations. The objectives of this study are: 1) Determine which ecological factors are responsible for the endemism of *A. rossiae*. 2) Determine the historical relationship between *A. rossiae* and *A. scabra*. A phylogenetic study based on molecular and morphological data will verify that *A. rossiae* is monophyletic and test the hypothesis that it is the sister taxon of *A. scabra*. 3) Use population genetic models, common garden, and greenhouse experiments to explain the geographic distribution of *Agrostis rossiae* and *Agrostis scabra* populations in terms of gene flow and natural selection. 4) Investigate plant speciation paradigms. Because of abrupt variations in soil temperature and other edaphic factors, Yellowstone's thermal communities are ideal locations for testing speciation theory. The spatial scale at which divergent selection pressures appear to act is well within the range at which cross-pollination and seed dispersal occurs. It is suspected that *A. rossiae* has been sympatrically derived from *A. scabra*.

Findings: During the summer of 1999, we cooperated with Park Service personnel in an effort to GPS map all known *A. rossiae* populations. We collected specimens of *Agrostis rossiae* and *Agrostis scabra* for genetic analysis. Soil temperature data were collected with data loggers located on transects that traverse the boundary between the two species. Soil samples and *Agrostis* seeds were collected. Common garden experiments were initiated. Genetic analysis and greenhouse experiments are in progress. Field work will continue in summer 2000. All plant specimens collected are housed in the Tulane University herbarium.

Project title:	**Assessing Ecosystem Integrity: An Approach Modeling Energy Flow**
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Additional investigators:	Diane E. Ashton, Peggy Wilzbach, Ken Cummins

Objective: 1) To compare wetland aquatic invertebrate production estimates and P/B ratios from stressed and non-stressed ecosystems; and 2) to evaluate the use of energy flow/flux in monitoring ecosystem integrity.

Findings: We have identified 187 taxa in samples from YNP wetlands. Of these, 131 (70%) had not previously been reported from the park. Community structure of aquatic invertebrates in wetlands was influenced by duration of flooding and presence of salamander larvae. A book chapter detailing these findings was published in 1999 and copies provided to the YNP Center for Resources. Collections are housed at the California Cooperative Fish Research Unit, Humboldt State University.

Project title:	**The Sustainability of Grazing Ecosystems**
Principal investigator:	Dr. Douglas Frank
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Additional investigators:	Peter Groffman

Objective: To determine the effects of large herbivores on plant production and nitrogen cycling in Yellowstone National Park.

Findings: Grazers increased aboveground production by an average of 20% at ten study sites that varied widely in elevation, soil properties, species diversity, and plant production. Below-ground production of grazed and fenced, ungrazed grassland is currently being assessed from monthly images captured from minirhizotron tubes. A growth chamber experiment on a common Yellowstone grass indicated that clipping stimulated root exudation (carbon), rhizospheric microbial biomass, net N availability, and plant tissue N content. These results suggest that this species is capable of "farming" its rhizospheric

microbial population to accelerate N availability and uptake. Roots of grasses growing inside and outside long-term winter range exclosures were stained to determine the intensity of mycorrhizal colonization. We found that ungulates had no effect on mycorrhizal infection rates at two time-points (early-May, mid-June) during the 1999 growing season. All plant collections will be donated to the Yellowstone herbarium upon completion of the project.

Project title:	**Climatic Variation in the Greater Yellowstone Ecosystem: Evaluating the Evidence for Decade to Centennial Variability in Climate**

Principal investigator:	Dr. Lisa Graumlich
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Additional investigators:	John King, Jeremy Littell

Objective: Develop a multi-species network of tree-ring data within the Greater Yellowstone Ecosystem to: 1) document and explain spatial and temporal climatic variability; 2) predict vegetation response to climate; and 3) increase scientific understanding of the processes and factors controlling forest dynamics.

Findings: Tree-ring collections made during 1999 yielded six 1000± year records and one 2000± year record of tree growth. Preliminary analyses demonstrate that the Greater Yellowstone Ecosystem tree-ring chronologies contain strong precipitation signals at both high and low frequencies. These results combined with a spectral analysis suggest that multi-decadal north Pacific atmosphere-ocean circulation features have been an important driver of regional climate over the past two millennia. Low frequency features in these chronologies provide preliminary evidence for persistent droughts that differ in timing compared to California drought reconstructions. As such, these data offer an important tool for understanding the spatial extent of severe droughts in western North America.

Projected research for 2000 includes: 1) 1000± year reconstructions of temperature and precipitation in the Northern Rockies; and 2) characterization of the relationships between multi-decadal climate patterns and ocean-atmospheric interactions.

Project title:	**Cougar-Wolf Interactions in Yellowstone National Park: Competition, Demographics, and Spatial Relationships**

Principal investigator:	Dr. Maurice Hornocker
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Additional investigators:	Toni K. Ruth, Howard Quigley

Objective: 1) Document interspecific killing and the characteristics of the cougar population, including population size, survival, cause-specific mortality and natality, and compare with analogous estimates made prior to wolf restoration (Phase I data; Murphy 1998). 2.) Assess competition, habitat, and food use characteristics of the two species. 3) Quantify spatial interactions between cougars and wolves. 4) Assess the effects of cougars on elk and mule deer populations as influenced by the presence of wolves. 5) Communicate research findings to state and federal agencies and the general public through annual technical reports, research updates, and presentations.

Findings: Hornocker Wildlife Institute (HWI) personnel captured and radio-collared 16 cougars in and adjacent to areas used by three wolf packs on the northern Yellowstone study area (NYSA), Montana and Wyoming. A sample of 3 to 10 radio-collared wolves was maintained within each wolf pack by the Yellowstone Wolf Project. Researchers associated with both HWI and Yellowstone National Park conducted aerial and ground monitoring of radio-instrumented animals. HWI field crews searched 1,589 km of track transects to conduct winter cougar sign surveys and provide an estimate of cougar population size. A minimum of 21 adult and sub-adult cougars were present on the NYSA during the 1998-1999 winter season. An additional 3,113.6 km were traveled by foot or snowshoe to conduct ground radio tracking, predation sequences, document prey kills, and search cougar location sites during the report period.

Two adult female cougars produced litters of three offspring (female F47) and two male offspring (female F105). Eight of 10 kittens associating with four separate family groups were radio-marked and monitored. An unmarked male (or males) killed two sub-adult male cougars in early spring, 1999. Both sub-adult males appeared to be establishing residency (scrapes and localization), but may have been potential dispersers.

Seventy-two positive and probable cougar kills were documented. Prey included 55 elk, 7 mule deer, 1 bighorn sheep, 4 coyotes, 4 porcupines, and 1 red squirrel. Three predation sequences of 26 to 35 consecutive days resulted in a mean predation rate of 8.4 days per ungulate kill for the 3 cougars sampled. Approximately 187 ground and 98 aerial locations were obtained on cougars. Five flights were coordinated with Wolf Project personnel to obtain simultaneous locations on cougars and wolves

for spatial-temporal analysis. A resource selection protocol for collection of site-specific habitat and prey information is under development.

Project title:	**'96 Field Course - Forest Ecology and Geology of the Yellowstone Country**
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Additional investigators:	Martin Knoll

Objective: The major forestry objectives are to 1) identify stands representative of the various forest habitat and cover types described by Despain (1990); 2) establish permanent plots within each stand; 3) develop a database of stand characteristics such as tree species composition, height, age, and understory composition for each plot; and 4) establish transects to investigate species gradients in relationship to thermal features. The plots will be used to illustrate the concept of habitat typing as applied to Yellowstone forests. The primary geology objectives are to 1) study temperature and pH gradients in Yellowstone Lake and representative hot springs; 2) characterize thermal features representative of different regions of the park; and 3) identify rock types characteristic of the major volcanic episodes in Yellowstone. The field course is taught during alternate years.

Findings: Several stands representing different lodgepole pine or Douglas-fir cover types were identified and dominant tree heights, diameters, and ages were recorded during the three-week field course in the summer of 1999. Sites visited in 1995 or 1997 were revisited and one new site was established. Vascular plant species lists were recorded along the Yellowstone Canyon rim, Pebble-Creek Trail, Hoodoos Trail, and the Black Canyon Trail and compared to previous years. GPS locations were recorded for the study sites to facilitate site maps. A temperature depth profile was recorded for Yellowstone Lake in the vicinity of Stevenson Island. Temperature and pH was compared along the stream and within a series of hot springs located near White Creek and near the upper terrace of Mammoth Hot Springs. The next summer field course is scheduled for August 2001. Sites visited on previous trips will be revisited, data updated, and new sites will be established.

Project title:	**Study of the Effects of the 1988 Wildfires on Yellowstone Stream Ecosystems**
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Additional investigators:	A. Marcus

Objective: The overall objective of this study is to separate the early from the delayed effects of wildfire on stream ecosystems in Yellowstone National Park. Specific goals include documenting changes in stream habitat and biota each successive year following the 1988 wildfires, thus providing a basis for predicting and evaluating subsequent long-term changes. Few streams greater in than size than 4th order were substantially affected by the fires, and this study focuses on streams of 1st through 4th order. To increase the breadth and precision of the study and to provide more general conclusions, each size class (order) is represented by four to five streams, as well as by at least one reference stream that was not affected by the fires.

Since 1993, the research has been limited to streams in the Cache Creek drainage basin, due to financial constraints. This has meant elimination from the study design of reference sites (except for Amphitheater) and much of the sampling replication. Nevertheless, samples from one of the most intensively burned watersheds (Cache) are being collected each year (other than 1996) through cooperation with Yellowstone Ecosystem Studies. However, in 1998 sampling of all the original sites was completed.

Findings: Although the effects of fire were evident in early years of this study, the streams could be characterized as being largely on a "fast recovery track." However 1991 and 1994 were marked by runoff events that caused substantial alteration of physical habitat in the streams in burned watersheds, particularly those in moderate to steep gradients. Even greater physical alterations occurred in 1995 (and probably in 1996) and were evident again in 1997. The dramatic changes in 1995-1997 are associated with a general increase in precipitation in those years. Disturbances such as these are reflected in declines in the biotic components of the stream and serve as important "resets" in the recovery process. However, as was evident from examination of one of our reference streams (Amphitheater) in 1997, some of those differences are more a response to a change in annual weather conditions than to fire per se. The analyses conducted to date indicate a substantial change in channel morphology (wider, more shallow) in the larger (3rd and 4th order) burned streams than in a similar size reference stream during the eleven years since the fire. In contrast, initial changes (narrower, deeper) in the smaller (1st and 2nd order) burned streams than in their reference streams have dissipated during that time. Periphyton (attached algae) and benthic organic matter did not show any consistent difference between burned and unburned streams but several aspects of macroinvertebrate community structure did. In general, densities were higher and percent Ephemeroptera-Plecoptera-Trichoptera (%EPT, a measure particularly

sensitive to disturbance) taxa were lower (=greater impact) in the burned streams than in the reference streams. These changes were accompanied by an increase in the proportion of smaller, more vagile taxa, suggesting a shift in community structure from K- to r-strategists. However, these differences did not exist for taxa richness or biomass, indicating that metabolic compensation accompanied the change in community structure. The results obtained thus far indicate that there still are discernable impacts in the burned streams eleven years after disturbance by wildfire.

Project title: **The Influence of Soil on Whitebark Pine (*Pinus albicaulis*) Cone Prodcution in the Greater Yellowstone Ecosystem**

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Additional investigators: Kathy Hansen, Bill Locke, Ward McCaughey, Chuck Schwartz

Objective: To determine to what extent the measured soil properties affect whitebark pine cone production.

Findings: This research examined the relationships between whitebark pine (*Pinus albicaulis*) cone production and soil properties and foliar nutrient levels. Cone count data were collected by the Interagency Grizzly Bear Study Team from plots across the Greater Yellowstone Ecosystem (1980-1999). The data used in this study came from eight of those plots (78 trees) and covered the years of 1989-1997. Soil properties measured included: electrical conductivity (EC), pH, percent coarse material, texture (percent sand, silt and clay), and percent organic matter and depth. Foliar nutrient levels were determined for the following nutrients: boron, calcium, copper, iron, potassium, magnesium, manganese, molybdenum, nitrogen, phosphorus, sulfur and zinc. These variables were regressed against cone production to determine their influence and significance. EC and pH both had significant positive correlations with cone production, and percent coarse material had a significant negative correlation with cone production. EC is a measure of the concentration of ions in solution, and in whitebark pine environments it can be used as an approximation of the amount of available nutrients. When soil pH levels approach neutral, more nutrients necessary to plants become available. Percent coarse material limits the amount of surface area on which nutrients or water may be held, and thus limits productivity. All other variables had no significant relationships with cone production. A multiple regression model using EC and pH significantly explained 38% of the variation in cone production. Percent coarse material was insignificant in the model because of its covariance with EC and pH, suggesting that it affected soil chemistry rather than water availability. A second multiple regression model, which used crown volume and EC, significantly explained 59% of the variation in cone production. Soil pH was not used because of its correlation with EC, and because EC had more predictive power. The information gained from this study could be used to assist in site selection for planting of whitebark pine and in

developing other management strategies that increase whitebark pine cone production and provide better wildlife habitat.

Project title:	**Statistical Methods for Assessing Complex Ecosystem Processes and Population Dynamics: A Case Study of the Yellowstone and Teton National Parks Shiras Moose**

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Objective: Houston described a complex process involving both environmental and population level variables that he believed were the ultimate determinants of moose population size. The objective of this study is to develop a statistical method capable of both testing and parameterizing the complex process envisioned by Houston. Structural equation modeling methods will be employed to construct a statistical model for this purpose.

Findings: This research presents an example of how SEM could be used to test a classic theoretical model of population dynamics of the Shiras Moose. A longitudinal model is developed in which population density is measured in two waves. The change in population density between the two periods of measure is modeled in relation to a complex set of interrelationships among environmental and population level variables. Included in the model are examples of composite variables and non-zero fixed parameters. Analysis of a simulated data set demonstrates the procedures of a typical SEM study in which analysis begins first with the analysis of a measurement model, and proceeds with a series of exploratory and confirmatory analyses. The use and pitfalls of fit statistics, t-values, modification indices, and Q-Q plots as diagnostic tools are demonstrated. Two types of estimates, maximum likelihood covariance estimates and standardized solution estimates, are contrasted. Examples of the calculation of total effects from direct and indirect effects are presented. Results demonstrate a significant potential for using SEM data analysis and simulation capabilities to develop expert systems and ecological models.

Project title: **Aspen Regeneration in Northern Yellowstone National Park**

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Additional investigators: Eric J. Larsen, Roy Renkin, Douglas Smith

Objective: Based on trophic cascades theory, the objective of this research is to gather data on how wolves may modify the spatial pattern and intensity of elk browsing on northern range aspen. Using YNP radio telemetry data on wolves and a fixed kernal estimate, we delineated polygons representing high-use winter activity areas of three of YNP's northern range wolf packs. These polygons were then overlain onto our northern range aspen inventory, and aspen were grouped into two categories: those stands containing a high density of wolf telemetry locations (inside of 50% fixed kernal estimate) and those lying in areas of lower densities of telemetry locations (outside of 75% fixed kernal estimate). A random selection of aspen stands was made from each of the two groups. Transects were established in the chosen aspen stands and data collected to study the following objectives: 1) to determine if there are significant differences in aspen sucker heights and elk densities (determined by elk pellet counts) between stands in areas of high winter use by wolves and in areas of lower use; 2) To establish permanent aspen plots and provide baseline data to study the long term influence of wolves on structuring aspen communities in the Yellowstone ecosystem.

Findings: During 1999, belt transects were established and field data collected from 113 plots on YNP's northern range. Differentially corrected GPS readings were taken for each sampled aspen stand. Each transect was 1x20 meters, starting from a random position on the edge of each stand. Heights of all aspen suckers within the transect were recorded and were classified as browsed, unbrowsed, or dead (based on the previous year's leader). The diameter at breast height of all overstory trees in the transect were recorded. A count of elk pellet groups was conducted in each transect. The generalized habitat type of each aspen stand was recorded using the categories of mesic upland steppe, xeric upland steppe, wet meadow, riparian, or scree/miscellaneous. The aspect, slope, elevation, topographic position, and recent fire history (burned/unburned) of each stand was recorded.

The data analysis is in the preliminary stages. To control for differences due to habitat type and site quality, the data will be separated into groups for analysis. Our research plan includes revisiting the plots every three years to establish a long-term record of changes to aspen communities on the northern range and the possible effects of predation on changing elk browsing patterns and behavior.

Project title:	**Causes and Consequences of Alternative Successional Trajectories Following the 1988 Yellowstone Fires**
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Additional investigators:	Monica G. Turner, Gerald A. Tuskan, Dennis H. Knight

Objective: 1) Predict and map the early successional pathways of areas burned in 1988 on the basis of percent serotinous lodgepole pine trees, size of burned patch, and local severity of fire. 2) Map percentage of serotinous trees across the landscape. 3) Measure aboveground net primary productivity and leaf area index in stands representing different initial pathways of plant succession following the Yellowstone fires of 1988. 4) Re-sample plant cover and density in the permanent plots established in 1990 within nine different patches of 1988 crown fire.

Findings: 1) We obtained 1:30,000 color aerial photos of the entire park in August 1998. Approximately 10% of the area that burned in 1988 now supports very high-density stands of 10-year old lodgepole pine trees (greater than 50,000 stems/ha); 10% supports very low-density lodgepole pine (less than 100 stems/ha); and the remaining burned area has stands of intermediate tree density. 2) Initial sampling of percent serotiny indicated highest percentages at lower elevations in the west-central portion of YNP, and lowest percentages in high-elevation forests in the central and eastern portions of the park. 3) Aboveground net primary productivity (ANPP) and leaf area index (LAI) were measured in 1999 in 88 stands that had burned in 1988. These fundamental measures of ecosystem function varied with sapling density, ranging from 0.9 - 12.6 metricton/hectare/year (ANPP) and from 0.03 - 4.6 m^2/m^2 (LAI).

Project title:	**Effects of Fire Size and Severity on Early Succession and Aspen Seedling Establishment**
Principal investigator:	Dr. William Romme
Phone number:	See previous entry
Additional investigators:	Monica G. Turner, Gerald A. Tuskan, Dennis H. Knight

Objective: 1) Sample density and survival of aspen seedlings throughout the areas burned in 1988. 2) Determine experimentally the effects of ungulate browsing, plant-to-plant competition, micro-climate, and genetics on survival and growth of aspen seedlings. 3) Measure plant cover, density, and diversity in permanent plots established in 1990 throughout the areas burned in 1988. 4) Predict and map the early

successional pathways of areas burned in 1988 on the basis of percent serotinous lodgepole pine trees, size of burned patch, and local severity of fire. 5) Map percentage of serotinous trees across the landscape. 6) Measure aboveground net primary productivity and leaf area index in stands representing different initial pathways of plant succession following the Yellowstone fires of 1988.

Findings: 1) Aspen seedlings are most abundant in burned forests of the western and west-central portions of Yellowstone NP, along the Madison and Firehole Rivers. 2) Experiments on the effects of browsing and competition are ongoing. So far the plants have shown relatively little response to protection from browsing or to removal of local competitors. 3) Trends in plant cover, density, and diversity that were measured from 1990-1993 generally continued through 1996. The permanent plots will be resampled in 2000. 4) We obtained high-resolution aerial photos of the entire park area in August 1998, and are using these photos to map areas that burned in 1988 and now exhibit high-density lodgepole pine, low-density lodgepole pine, or non-forest vegetation. 5) Initial sampling of percent serotiny indicated highest percentages in the west-central portion of Yellowstone NP. 6) Productivity and LAI will be sampled in 1999.

Project title: **Sagebrush Ecology and Ungulate Relationships**

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Objective: 1) To determine the current status of the sagebrush-shrub community on the northern Yellowstone mule deer winter range. 2) Determine the importance of the sagebrush-shrub community to wintering mule deer and elk. 3) Describe the effect of human-caused and natural fire, including interactions with browsing, on sagebrush ecology on the northern Yellowstone winter range. 4) Determine what management techniques can be implemented to preserve or enhance mule deer and elk habitats associated with sagebrush-shrub communities.

Findings: Mule deer utilize the several sagebrush habitat types in the boundary line area as key wintering types. They use the four woody sagebrushes and three rabbitbrushes heavily as browse, although they display a decided preference among taxa on winter range. None of the sagebrushes have reestablished very well following burning as long ago as 19 years. The rabbitbrush taxa have responded to burning somewhat better, but heavy browsing has not allowed them to attain a very significant role in their respective habitats. Some mountain big sagebrush plants establish most years but some years are

enormously more important for establishment of the taxon. Communities of older sagebrush plants are more productive than those of younger plants. Sagebrush production can be modeled using taxon and form class with great accuracy. Significant differences exist in the development of protected and browsed shrubs of big sagebrush habitat types. Preliminary information indicates that wildfires and ungulate browsing interact as determinants of sagebrush recovery. The actual degree of interaction varies among sites that differ in environmental conditions.

Project title:	**Community Position and Pattern along a Continuous Thermal Gradient: Physical and Biological Constraints**
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Objective: The objective of the current phase of the project is to follow the long-term dynamics of the organisms in thermal communities in the temperature range from 45° C down to ambient.

Findings: During the past year research activities at Yellowstone National Park included continued censuses of emerging adults of the dragonfly (*E. collocatus*) and whole system censuses of selected thermal communities located in West Thumb, Upper, Midway, and Lower Geyser basins and areas along the road from Madison Junction to Mammoth Hot Springs. I also spent a small amount of time searching other, more isolated thermal areas for thermal communities unusual in terms of either temperature/nutrients or animal/plant species. No additional sites were added last year. A paper on the comparative ecosystem work is nearing completion. In addition, during the past year I wrote a review of thermal biodiversity that is in press for the upcoming *Encyclopedia of Biodiversity* by Academic Press.

One objective of the current research is to compare long-term variability in the systems. A second objective is to explore the variability with the various classes of thermal community, i.e., hot (greater than 40° C), warm (less than 40° C) and, within this classification, the water chemistry, i.e., alkaline or acid.

The dragonfly census work is done in Gentian Stream, Serendipity Meadow just off of Firehole Lake Drive in the Lower Geyser Basin. I now have 20 years of total emergence counts and am trying to get temperature/precipitation data from the Old Faithful weather station to see if the large year-to-year variability in production of adults is related to weather. I have also begun to measure stream and local air temperatures with data loggers in place all year. Two papers on this work are started, but will require at least two-three more years of data.

ENTOMOLOGY

Project title: **Butterflies of Greater Yellowstone; Aquatic Insects of Greater Yellowstone**

Principal investigator: Dr. Robert Anderson
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Idaho State University
Pocatello, ID 83209

Objective: In conjunction with two courses taught for the Yellowstone Institute at Lamar Ranch one week in early July 1999, sample butterflies and aquatic insects in the northern sector of YNP, and from Gardiner, Montana, to Beartooth Summit. Specimens collected from meadows, fields, and ponds and small streams are to be catch and release only.

Findings: Butterflies representing six of the seven families of *Rhopalocera* were identified. These observations included two species of *Papilionidae* (including numerous parnassians), several species of *Pieridae*, *Satyridae*, *Nymphalidae*, *Lycaenidae*, *Hesperiidae* (sixteen species). A special effort was undertaken to identify the Yellowstone Checkerspot butterfly in the northern region, but none were found. Sex ratio information collected for parnassians indicated a predominance of males: 22M/lF.

Samples of aquatic insects collected from various streams and glacial ponds in the northern region were similar in species composition and diversity to collections made in previous years, with approximately eight species of *Trichoptera*, several species of *Plecoptera*, about six species of *Ephemeroptera*, plus varied species of *Odonata* and aquatic diptera. All specimens obtained in the park were released at point-of-capture following in-field discussions.

Project title:	**Mosquito Distribution Correlated with Elevation, Habitat, and Temperature**
Principal investigator:	Patricia Denke
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Email:	*pmdenke@montana.edu*
Address:	Montana State University Entomology Room 333 LJH Bozeman, MT 59717
Additional investigators:	Greg Johnson

Objective: The objective of this research is to determine if certain species of *Aedes* mosquitoes are restricted by selected habitat variables, including water temperature and pH, elevation, and habitat (in terms of shading and vegetation). A secondary objective is to determine if the species are associated with each other in any significant ways.

Findings: No additional samples have been taken, although the addition of *Culicoides* (another small dipteran that is frequently found in the mud around the edges of more or less temporary pools) should have resulted in additional materials. At this point, the mosquito data are being analyzed and summarized. Total completion of this project is anticipated during 2000.

Project title:	**Butterflies of Yellowstone and Grand Teton Park (also Odonata)**
Principal investigator:	Richard Lund
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Address:	Consultant Services Northwest Inc. 6521 36th Ave NE Seattle, WA 98115-7427
Additional investigators:	Mardell Oleta Moore

Objective: To produce field guides about the insects of Yellowstone and Grand Teton national parks. Photographs need to be taken of all species in the parks. Data & photos only need to be obtained. No specimens are collected. All specimens are safely netted, photographed and released live in the area of the park where they were discovered by the researchers.

Findings: In 1999, 16 slides of dragonflies and damselflies were taken. The species include: four spotted skimmer, mountain emerald, western pondhawk, twelve spotted skimmer, paddle tailed darner,

red skimmer, common whitetail and tule bluet. Copies of all slides taken are donated to the museum located at the Albright Visitor Center in Yellowstone National Park. Our fieldwork in 1999 has led us to believe that one can expect to find from one to a maximum of three different species of dragonflies on each wet area inventoried so far. It will take a lot of fieldwork to cover the numerous wet areas in the park to discover all the possible species present within the park.

Project title: **The Mosquitoes of Yellowstone National Park, A Study of the Species and their Biology**

Principal investigator: Dr. Lewis T. Nielsen
Phone number: 801-277-2055
Address: 4835 S 2120 E
Salt Lake City, UT 84117-5378

Objective: A continuing study of the Yellowstone mosquito fauna, species distribution and ecology.

Findings: A visit to the park in 1999 during the month of August resulted in presence of very few adult mosquitoes. However, collections of larvae in July resulted in a new record for the park (*Aedes communis*). Yellowstone now contains 30 species.

Project title: **Assesment of Host Races in the Ovary-Feeding Beetle, *Brachypterolus pulicarius* (Coleoptera: Nitidulidae)**

Principal investigator: Dr. Robert Nowierski
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Bozeman, MT 59717-3020

Additional investigators: Kelly Hering, Bryan FitzGerald

Objective: This research is being completed for Kelly Hering's master's thesis project at Montana State University, investigating the existence of host races in the beetle, *Brachypterolus pulicarius*, a natural enemy of yellow and Dalmation toadflax. Because this beetle exists on two separate host plants, I am investigating whether the species consists of two genetically distinct host races. In choosing sites to collect the insects and plant material, I sought sites where the insects have never been released as a biological control agent. Rather, they were accidentally introduced along with the weeds. Because *B. pulicarius* has never been introduced into Yellowstone, and because both yellow and D. toadflax infestations are present, the park offers an excellent opportunity for collecting the insects as they naturally occur on the

two hosts. Along with the sites in Yellowstone, others in Canada and the northeastern United States will be analyzed.

Findings: On August 26, 1999, Bryan FitzGerald and Kelly Hering met Craig McClure, a park ranger, to sample several toadflax sites. Insects and plant material were collected at five separate sites, taking a total of about 50 insects and 15 plant stems. Insects from both yellow and Dalmation toadflax were collected, and placed into alcohol to be preserved for use in genetic analysis. All insects collected will be consumed during the course of the genetic research.

In the months since collecting, an extensive literature review and research of various genetic techniques has been conducted. Recently, the lab began utilizing a DNA extraction protocol, the first step of genetic analysis, and has had success with the technique. We intend to use the Amplified Fragment Length Polymorphism (AFLP) technique for genetic analysis of intra-specific variation in the samples.

Project title: **Respiratory Physiology and Habitat Selection in Thermophilic Aquatic Insects**

Principal investigator: Dr. Brent Ybarrondo
Phone number: 719-587-7481
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Address: Adams State College
Department of Biology
Alamosa, CO 81002

Objective: Understand respiratory physiology and habitat selection decisions in thermophilic aquatic insects, including water scavenger beetles (Coleoptera: Hydrophilidae) and both adult and nymphal stages of dragonflies and damselflies (Odonata). Correlate habitat selection decisions and thermal preference with respiratory physiology and development (Odonata).

Findings: Odonate niads from thermal pools were found to exhibit thermal preference in the laboratory. Hydrophilid respiratory complex (plastron + macroplastron, or bubble) functions primarily as an oxygen reservoir at water temperatures greater than ca. 5° C. Future research will investigate: 1) the degree to which the respiratory complex function as a physical gill at low water temperatures (ca. Tw = 0 to 5.0° C); 2) the degree to which adult male dragonflies exhibit thermal preference in controlling oviposition territories in thermally variable environment (e.g., Firehole Rive study site); and 3) development rates of odonate niads as a function of water temperature and dissolved oxygen tension. Findings to date were presented as an invited speaker at the Entomological Society of America national meeting in December 1999 as part of a symposium entitled: "Life on the Edge: The Physiology, Ecology, and Evolution of Insect Thermoregulation and Temperature Tolerance."

ENVIRONMENTAL MONITORING AND GIS

Project title: **A Remote Sensing and GIS-Based Model of Habitat as a Predictor of Biodiversity**

Principal investigator: Dr. Diane Debinski
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Ames, IA 50011

Additional investigators: Mark Jakubauskas, Kelly Kindscher

Objective: The major objectives of the research were to: 1) Quantify the spatial and temporal variability in montane meadows. 2) Develop a spectrally-based spatially-explicit model for predicting plant and animal (butterflies and birds) species diversity patterns in montane meadows. 3) Test the spectrally-based spatially-explicit model for predicting plant and animal species diversity patterns in montane meadows.

Findings: We sampled birds, butterflies, and plants for three years (1997-1999) in two regions of the greater Yellowstone ecosystem: the Gallatin National Forest and northwestern portion of Yellowstone National Park and Grand Teton National Park. We used satellite imagery to classify two types of wetland meadows and four sagebrush communities. In Grand Teton National Park, our overall accuracy of mapping sagebrush communities was 65%, and the highest for the mixed big sagebrush/low sagebrush community was 86%. Abundance of habitat specialist bird species was highly correlated with both meadow type and landscape variables. Butterfly species abundance and distribution was even more strongly correlated with meadow type (butterfly distribution was used to predict meadow type with a 92-96% accuracy in the Tetons). Voucher plants are housed at the University of Kansas McGregor Herbarium; voucher butterflies are housed at Iowa State University.

Project title: **Chloride Flux Monitoring**

Principal investigator: Dr. Irving Friedman
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D.F.C., MS 963
Denver, CO 80225

Additional investigators: Daniel R. Norton

Objective: To provide a baseline for chloride flux exiting the park. Chloride flux is a proxy for heat flux.

Findings: Chloride flux, a surrogate for heat flow, was determined for the four rivers draining Yellowstone National Park for the water years 1983 through 1999, with the exception of 1995 and 1996. Using our measured average chloride flux to calculate annual heat flow from Yellowstone results in a value that is 20% greater than that calculated by Fournier et al., 1976. The Fall, Madison, Snake, and Yellowstone rivers have been estimated to discharge 94% of the chloride leaving the park. The flux for each river varied seasonally and annually, and is postulated to depend primarily on the flow of hot springs, which in turn depends on the height of the local water table, which rises during spring runoff, and varies annually in synchronism with changes in annual precipitation. The sum of the annual chloride fluxes for these four rivers varies as much as 20% from year to year. In support of the hypothesis of the influence of the height of the water table on the discharge of hot springs, chloride flux data collected during the fires of 1988 show that a large increase occurred in discharge of constant chloride concentration of Mammoth Outflow, a thermal stream of high chloride concentration that drains the surface features of Mammoth Hot Springs. These changes are explained by variations in the height of the local water table caused by the addition of large quantities of low-chloride water used to suppress the fire, rather than dilution of Mammoth Outflow by the direct addition of water.

Project title: **Remote Sensing-Based Geostatistical Modeling for Coniferous Forest Inventory and Characterization**

Principal investigator: Dr. Mark Jakubauskas
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Lawrence, KS 66045-2969

Additional investigators: Clayton F. Blodgett, Edward A. Martinko, Kevin P. Price

Objective: The goal of this research is to develop, test, and demonstrate an integrated remote sensing

and geostatistical approach for the analysis of forest canopy structure, secondary forest regrowth, and forest fire history that takes advantage of the spectral and spatial correlation of ground phenomena and remotely sensed information. The project has four objectives: 1) Development of geostatistical models for forest biophysical parameters (height, density, basal area, leaf area index, and biomass) using multiscale satellite imagery and field data. 2) Calibration and verification of the models by field data and statistical means. 3) Testing the models in two specific forest characterization and inventory applications (forest cover type mapping and insect damage assessment). 4) Dissemination of the algorithms and procedures to the user community via online tutorials and software modules. Initial model development will focus on the lodgepole pine forest of the Greater Yellowstone Ecosystem

Findings: Key milestones achieved:
- Major summer 1999 field campaign in Yellowstone National Park – 330 sites sampled for forest biophysical characteristics
- Postdoctoral researcher hired
- LANDSAT 7 Thematic Mapper data of Yellowstone for July, August, September 1999 acquired from EROS Data Center and processed
- Project web page developed and is online: *www.kars.ukans.edu/forest*

Planned work for summer 2000 includes additional forest sampling in the eastern Central Plateau to complete the field data set. During 2000-01, model development will continue, leading to field work in summer 2001 directed toward field checking of model predictions of forest parameters.

Project title: **Trace Element Content of Cervid Antlers**

Principal investigator: Dr. Jack Kovach
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New Concord, OH 43762

Objective: I am studying the strontium isotopic composition and the content of strontium and other trace elements in elk and deer antlers from selected national parks in the western U.S., including Yellowstone. The study will add to the general body of knowledge about the cycling of trace elements through the environment and increase our understanding of the biogeochemistry of strontium. The study will provide baseline data from which future changes may be gauged.

Findings: No significant findings to date with respect to trace element contents inasmuch as no analytical data are yet available. Evidence of antler-chewing/osteophagia by Yellowstone elk has been obtained, and this is likely related to the major and/or trace element content of the antlers/bones and the nutritional status of the elk. Fieldwork by me in the park in August and October l999 was directed primarily toward determining the geographic distribution and frequency of occurrence of antler-chew-

ing/osteophagic behavior through field observations of skeletal remains of dead animals and cast (shed) elk antlers, mostly on Yellowstone's northern range.

Project title:	**Development of Algorithms to Use with Satellite Images to Assess Annual Snow Melt and Green-Up in Yellowstone National Park**
Principal investigator:	Dr. Rick Lawrence
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Address:	Land Resources and Environmental Sciences Mountain Research Center Montana State University Bozeman, MT 59717
Additional investigators:	Donay Hanson, Kathy Hansen, Richard Aspinall

Objective: This thesis is a methodology for use in conjunction with satellite imagery to determine snow cover and green-up in Yellowstone National Park that can be used on a near real-time basis. The methodology includes an ARC Macro Language (AML) in ARC/INFO or an Avenue Script in ArcView to perform the algorithms that accurately identify changes in snow cover and green up. They will be accompanied by a descriptive text including instructions for use and assumptions. The overall objectives of the study are to use satellite imagery and, 1) develop a method to determine percent of ground covered by snow and changes in forage quantity (green-up); and 2) test the utility of the method to determine the relationship of snow cover and green-up to ungulate distribution.

Findings: Ground data was collected and is currently being analyzed. Preliminary analysis indicates that AVHRR band 5 most accurately predicts percent snow cover; however, further analysis is necessary. No results are available for the green biomass portion of the study at this time. The study is on schedule with completion of an AML scheduled for mid-February 2000.

Project title:	**The Impact of Bison in Riparian Areas of Soda Butte Creek in the Lamar Valley**
Principal investigator:	Jody Millette-Larned
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Address:	8895 Aragon Drive Colorado Springs, CO 80920

Objective: The purpose of this research was to determine if the northern bison (*Bison bison*) herd in the

Lamar Valley of Yellowstone National Park was negatively impacting riparian ecosystems in the area of Soda Butte Creek. Relationships between the bison and two of the components of the creek's riverine environment, soil, and vegetation were examined, including the topographic and geologic factors influencing those components.

Findings: I concluded that the bison were not damaging riparian areas of Soda Butte Creek. However, the study was limited by parameters such as a static bison population, small study area, and a relatively short period of field research. A longer-term study conducted parkwide and contingent upon future bison management policy would be necessary to definitively determine whether bison are indeed damaging riparian or any other ecosystems within Yellowstone National Park.

Project title: **Hydrogeomorphic Approach to the Assessment of Wetlands in Yellowstone National Park**

Principal investigator: Chris Noble
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Additional investigators: Marcus Miller, Bob Leinard, Forrest Berg

Objective: We collected data in five depressional wetlands in Yellowstone National Park. This data will be added to an existing database from Ninepipes National Wildlife Refuge and the Bandy Ranch. We collected data in the park due to lack of human disturbance and the probability that the wetlands sampled will remain in an undisturbed condition for reference purposes.

Findings: We have completed 100 percent of the data collection planned. We hope to collect data on two slope wetlands in 2000.

Project title:	**Inventory of Wyoming Resources**
Principal investigator:	Dwane Van Hooser
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Address:	U.S. Forest Service 507 25th Street Ogden, UT 84401
Additional investigators:	Michael Wilson, Bill Dunning, Dana Lambert

Objective: To collect information on the condition of forest ecosystems, estimate baseline (current) conditions and trends, and detect changes from those baselines and trends over time at the state and national level.

Findings: The inventory of Wyoming resources began in 1997 with installation of the ground locations. The installation was completed that same year and approximately 1/3 of the locations are re-measured each year thereafter. This project has no conclusion; therefore, there is no project ending date.

EXOTICS

Project title: **Assessing the Expansion Risk of an Exotic Snail across Habitats**

Principal investigator: Dr. Mark Dybdahl
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Ohio University
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Additional investigators: Billie Kerans

Objective: Collection of an exotic species of snail (*Potamopyrgus antipodarum*), estimates of their density in different locations, measurement of genetic (clonal) diversity of invading populations, estimates of their life-history characteristics, preliminary assessment of their effect on native aquatic macroinvertebrates, and establishment of sites for future monitoring.

Findings: We established experiments to examine competition between mud snails and native macroinvertebrates, and the impact of mud snails on periphyton density. To continue the study of invasion potential, I am studying life-history traits of mud snails under ambient conditions alongside temperature data loggers. We placed data loggers in the Firehole River, Fairy Creek, and at two invasion fronts: Iron Spring Creek and Little Firehole River. At sites with temperature loggers, I placed specific size classes of mud snails in cage enclosures and collected these cages later to measure growth and reproductive rates under a measured temperature regime. These cage experiments will continue during each season. One goal is to determine limiting conditions for mud snail growth and reproduction. Samples are currently housed at Ohio University and Montana State University.

Project title: **Evaluating Impacts of an Introduced Biological Control Agent, the Seven-Spotted Ladybird Beetle, on Native *Coccinella* in Natural Areas of the Northern Rocky Mountains**

Principal investigator: Dr. Kim Keating
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AJM Johnson Hall
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Bozeman, MT 59717

Additional investigators: Michael Ivie, Donna Ivie, George Markin

Objective: 1) Better document geographic extent of invasions of seven-spotted ladybird beetle (*Coccinella septempunctata*) (C-7) in northern Rocky Mountain national parks. 2) Estimate and compare historical vs. contemporary relative abundances of *Coccinella* species in these areas. 3) Identify species of *Coccinella* that may have been impacted by invasions of C-7. 4) Provide baseline data for assessing impacts of other exotic ladybird beetles (particularly, *Harmonia axyridis*) that are known to be expanding their range and which may ultimately have significant impacts on native species. 5) Help identify appropriate research and/or management responses in light of the above findings.

Findings: In 1999, 1,257 specimens of eight *Coccinella* species were collected in Yellowstone Natioanal Park and curated at Montana State University. Sixty-one historical specimens were examined in various museums. The exotic *C. septempunctata* (C-7) comprised 62% of the 1999 specimens. Relative abundances of two native species declined significantly ($P < 0.05$) after invasion by C-7. Historically, *C. novemnotata* and *C. trifasciata* comprised 16% and 31%, respectively, of *Coccinella* collected in YNP; but only 0.2% and 1%, respectively, of *Coccinella* collected in 1999. Relative abundances of five other native *Coccinella* species showed no changes, but the power to detect change was low for four of these due to small historical sample sizes. We conclude that C-7 has had a major adverse impact on native *Coccinella* in YNP. Results from other northern Rocky Mountain parks are consistent with this conclusion. A final report is in preparation.

FIRE

Project title:	**Fire - A Force for Change and Regeneration in Natural Ecosystems: An Instructional Module**

Principal investigator:	Dr. John Burger
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Address:	Department of Zoology Spaulding Hall University of New Hampshire Durham, NH 03824

Objective: To study natural regeneration of lodgepole pine and other vegetation following fires of varying intensity and to document the magnitude of change through time. Also to document pre-fire conditions in selected sites, compare pre-fire and post-fire landscapes following the 1988 fires, develop teaching modules for biology and plant community ecology courses.

Findings: This is the 11th year of the project, and during that time, I have established six sites for monitoring the annual changes in growth and reproduction of lodgepole pine. This includes collecting data on yearly growth rates of saplings and the onset and rate of reproduction in saplings. In addition, 14 photographic sites have been established in areas subject to different burn intensities. These sites are re-photographed every three years to record changes in the vegetation since the 1988 fires. Also included are sites in the Lamar backcountry that were studied in 1966-67, and were subject to varying burn intensities. Other post-fire sites were initially photographed in 1959-1967 and have since been re-photographed following the fires to demonstrate the magnitude of change. All information generated to date has been incorporated into fire ecology teaching modules for biology and plant community ecology courses.

Project title: **Post-Burn Resource Selection, Physiological Condition, and Demographic Performance of Elk**

Principal investigator: Dr. Robert Garrott
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Biology Department
310 Lewis Hall
Bozeman, MT 59717

Objective: The primary objective of this research is to evaluate the consequences of the 1988 fires on elk resource selection. Selection is being quantified for populations and individuals at multiple scales ranging from selection of patches within the landscape mosaic to selection of forages and plant parts within patches. The physiological and demographic consequences of observed resource selection strategies are being assessed through noninvasive urinary and fecal assays, and telemetry. Secondary objectives include basic research on forage plant chemical compositions, plant-animal interactions and applied research to develop practical and rigorous management tools for population monitoring (aerial surveys, fecal steroid pregnancy assays, and snow-urine condition indices).

Findings: We have been successful in developing, testing, and applying a suit of research tools that is significantly enhancing our ability to address questions of animal resource selection and the physiological and demographic consequences of selection patterns. We have completed our eighth field season of data collection and maintain an instrumented population of 30-40 cow elk. Most publications to date have focused on techniques including population estimation, pregnancy assessment, and nutritional indices. This year we completed a manuscript analyzing the demographic data collected during the first seven years of research which is currently being considered by J. Appl. Ecol. Adult survival and reproduction is near the biological maximum for the species, but recruitment is highly variable, being strongly influenced by environmental variation, primarily winter severity. Despite this variable recruitment, extensive Monte Carlo simulations indicate that the population is relatively stable and is being regulated at approximately 600-800 animals. We have generated a database of greater than 7500 animal locations and are exploring a variety of analytical tools for the analysis of these data. An ArcView GIS database has been developed that integrates landscape features with all spatially-explicit databases collected on this study. We are currently developing spatially-explicit snowpack models in collaboration with NASA scientists to enhance our analyses of elk resource selection.

Project title: **Impact of Fires of 1988**

Principal investigator: Dr. Daniel Norton
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Federal Center
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Objective: Annual studies of foliage, ash, and soil to track the changes in physical and chemical properties of collected materials. Sleve tests of ash and soil. Visual microscopy of ash and soil separates. Photographic records of selected sites, measurement of ash layer, description of site.

Findings: The sites on level terrain for the most part continued to reveal an average of 0.5 inch of black ash with small variation year by year. These sites were on forested terrain. Deviation from this result occurred on slopes that were washed by rainfall and on coarse soils in open terrain exposed to wind. Most dramatic is the marked increase of grasses, shrubs, and plants in the sites of level terrain in wooded areas containing considerable moisture.

Project title: **Yellowstone Post Fire Effects Plot Installation**

Principal investigator: Yellowstone Fire Program
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Address: Fire Cache
P.O. Box 168
Yellowstone NP, WY 82190

Additional investigators: Jim Kitchen, Steven Petrick-Underwood, Janet Hobby

Objective: The goal of the Yellowstone fire effects program is to monitor immediate post-fire and long-term trends in vegetation and fuel loading from prescribed and natural fires in the park. This year, 15 fire effects plots were established in Yellowstone at Electric Peak (8), Grant (6), and Rescue Creek (1) proposed burn units. These plots will be re-visited two months and two, five and ten years post-fire. Results will be used from burned plots and control plots to validate prescribed fire goals and objectives, refine burning prescriptions, improve fire prediction models, and monitor the effects of natural fires on vegetation.

Findings: None of the plots installed in 1999 were burned or ignited, though at least six plots (in the Grant unit) are proposed for 2000. Post-burn data is obviously not yet available, however some baseline data on fuel loading and vegetative components were generated from the initial read. Species lists and

specimen collections were created to assist with field identification.

For each plot, data such as fuel loading (tons/acre) by size class, mature tree diameters, seedling counts, duff and litter depths, relative cover of species, percent of native and non-native species, brush density and age by species, tree damage, and stems per acre were collected and analyzed. Changes in this baseline data will be measured and additional variables (such as mortality, scorch height, and burn severity) will be monitored post-burn (within the next five years).

Project title:	**Postglacial Fire Frequency and its Relation to Long-Term Vegetational and Climatic Changes in Yellowstone National Park**
Principal investigator:	Dr. Cathy Whitlock
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Email:	*whitlock@oregon.uoregon.edu*
Address:	University of Oregon Department of Geography Eugene, OR 97403

Objective: The primary objective has been to study the vegetational history of Yellowstone and its sensitivity to changes in climate and fire frequency. To establish a vegetational history, a network of pollen records, spanning the last 14,000 years, has been studied from different types of vegetation within the park. A reconstruction of past fire frequency is based on information gained from: 1) a study of the depositional processes that incorporate charcoal into lake sediments; 2) a comparison of charcoal and dendrochronologic records of fire occurrence during the last 750 years; and 3) an analysis of charcoal, pollen, and magnetic properties in lake sediment cores spanning the Holocene and late-glacial periods.

Findings: Progress was made on three aspects of this project. First, revision of the Trail Lake record is underway, based on the results of radiocarbon dating and tephra analysis, which indicate that the Trail Lake record is only 8,000 years old. The results of the charcoal, pollen, and magnetic susceptibility analysis using this revised chronology were presented at the 5th Biennial Science Conference on the Greater Yellowstone Ecosystem, and at annual meetings of the Ecological Society of America and the Geological Society of America.

Analysis of the sampling of modern sediments in lakes with watersheds that were burned in 1988. This process-based study provides information necessary to interpret the charcoal record in sediment cores, by determining the time of charcoal accumulation following a fire event. The study is unique, and the results have been used by fire researchers around the world. The samples are being evaluated in light of previous results and are discussed in two manuscripts that describe charcoal depositional processes.

Third, we are collaborating with scientists from the U.S. Geological Survey to evaluate the

paleolimnologic response of Yellowstone lakes to past climate change. Samples have been analyzed for sediment geochemistry. Special attention has been directed to northern range lakes, particularly Crevice Lake, which has annually laminated sediments. Plans are underway to core Crevice Lake in 2000. Other accomplishments of note are: 1) acceptance of the fire history from Cygnet Lake in *Geology*; 2) submission of manuscript on the paleoecologic record of plant invasions to *Western North American Naturalist*; 3) acceptance of two chapters on charcoal methodology; 3) submission of a chapter on the prehistory of the Rocky Mountains, with an emphasis on the Yellowstone region. Chapter will appear in *Rocky Mountain Futures*; and 4) presentation of results at the Biennial Scientific Conference in Yellowstone in October 1999, and at annual meetings of the Ecological Society of America, and the Geological Society of America.

Project title:	**Assessment of Secondary Mortality in Lodgepole Pine Stands in Yellowstone National Park Using LANDSAT Data**
Principal investigator:	Dr. Hans Zuuring
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Address:	University of Montana, School of Forestry Missoula, MT 59812
Additional investigators:	L. Kurtzhals

Objective: 1) Quantify and map the spatial distribution of secondary lodgepole pine mortality in Yellowstone National Park resulting from mixed burns or underburns. 2) Model the additional lodgepole pine tree mortality detected in 1991 based on changes in spectral characteristics of LANDSAT imagery between 1991 and 1988 as well as factors such as soil parent material, topography, site and stand characteristics. 3) Validate the mortality model through the use of color and infrared aerial photos and field data gathered from line transects.

Findings: From preliminary fieldwork in the summer of 1999, we identified a heterogeneous burned area about 9,300 ha in size located in the Lakes Region and in the old Snake River Complex Fire of 1988. This is a high elevation plateau at about 8,200 feet and is near a grizzly bear management area. It is an ideal area containing vegetation that exhibits various stages of lodgepole pine mortality. From aerial photography, we were able to determine exact locations of future survey lines to be established during the summer of 2000. We also field checked for validation previously developed secondary lodgepole pine mortality classes that had been delineated from 1:24,000 scale color aerial photos. Additional attempts were made to acquire previous research and field data that would prove useful as auxiliary data to our project. We have performed some preliminary image processing to generate NDVI and wetness index maps. By keeping an updated list of relevant literature, we are informed about the latest in remote sensing which will help guide our research towards completion. In future months, we plan to continue our visits to Yellowstone to meet with park officials, continue collecting resources, acquire other useful data sets, and interpret aerial photos, which will prepare us for our summer fieldwork.

FISHERIES MANAGEMENT

Project title:	**Le Hardy Rapids Yellowstone Cutthroat Egg Collection for the Development of Species Specific Brood Stock for Drainage Restoration**
Principal investigator:	James Barner
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Additional investigators:	Joe Gillis, Steve Sharon, Dave Miller, Paul Kretschmar

Objective: To collect and fertilize eggs for Yellowstone cutthroat trout pairs to develop a captured brood stock program. Eggs will be collected from the population that inhabits the Yellowstone Lake to Upper falls. Fish management staff at Yellowstone have also asked for egg collection on various other tributaries to aid in whirling disease research. The primary capture location will be Le Hardy Rapids, although other sites within the drainage may be considered if catch rates do not meet objectives. The original objective each year was to collect a partial spawn from a minimum of 25 pairs for consecutive years (1993-1996) for the purpose of stock recruitment of a brood stock to be held at Clark's Fork Fish Hatchery. This brood stock will be used for drainage restoration of the endemic range of the Yellowstone River in Wyoming and will also assist in the restoration projects in Montana.

Findings: We have had excellent cooperation with YNP personnel in accomplishing our goals with this project. This is the last anticipated year of the consecutive year collection process. Year 2000 collection will assure the brood stock adequate year classes for its development. We will then return to YNP every three to five years to infuse new genetic material from the Le Hardy Rapids stock into our Clark's Fork Fish Hatchery stock to assure good genetic representation of this stock.

Project title: **Collection of Gametes from Wild Stock Lewis Lake Lake Trout to Establish a Captive Broodstock to Support Lake Trout Restoration in the Great Lakes**

Principal investigator: Dr. David Erdahl
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Additional investigators: Ed Stege

Objective: The overall objective of this research project is to capture and spawn a minimum of 50 pairs of Lewis Lake lake trout in both calendar year 1999 and 2000. Fertilized eggs will be transported to the Saratoga National Fish Hatchery, Wyoming, for the establishment of a captive broodstock. Progeny from the Lewis Lake captive broodstock at Saratoga NFH will then be used for lake trout restoration/ recovery programs in the Great Lakes. This project is part of an ongoing effort that was initiated in 1983 with respect to utilizing Lewis Lake lake trout for lake trout restoration in the Great Lakes. Genetic considerations mandate an infusion of wild genes into captive broodstocks on a regular basis to insure the genetic integrity of broodstock populations.

Findings: Although past efforts had utilized electroshock techniques for fish capture, gill net sets were used in an effort to reduce incidental fish mortality. Although some mortality was observed, general consensus with respect to gill net utility was positive. Although only 24 paired matings were effected, eggs collected from a number of the larger females were split and fertilized individually with milt from different males, resulting in a total of 39 genetically distinct egg lots. All egg lots were transported to the Saratoga NFH and are being held in quarantine until the completion of disease testing on ovarian fluids collected from all spawned females, and a complete disease evaluation of resultant fry. Samples of fin tissue were also collected from 28 adult Lewis Lake lake trout. The USFWS is currently pursuing funding for a complete genetic evaluation of these samples.

Project title:	**Cutthroat Trout Egg and Sperm Collection**
Principal investigator:	Daryl Hodges
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Address:	Yellowstone River Trout Hatchery P.O. Box 508, Fairgrounds Road Big Timber, MT 59011
Additional investigators:	Montana Fish, Wildlife & Parks Personnel

Objective: To successfully manage Montana's fishery resources we need to maintain our hatchery broodstocks with a wide genetic diversity. These broodstocks should mirror their wild ancestors as closely as possible. The original gametes for our Yellowstone cutthroat trout broodstock came from McBride Lake in Yellowstone National Park in 1969. The last time gametes were taken from the lake to supplement the broodstock was 1987. To once again infuse our broodstock with new genetic material, we will collect gametes from Yellowstone cutthroat trout in McBride Lake for three consecutive years, beginning in 2000. We will take gametes from 10 pairs of fish each year. Health and genetic samples will be taken from the same fish.

Findings: A permit for egg collection was received in 1999. Due to high snow pack and late run off it was not possible to get the gametes in the spring of 1999. Montana Fish, Wildlife, and Parks' fishery biologists, hatchery employees, and Fish Health biologists are prepared to go to McBride Lake in June of 2000 and the following two years.

Project title:	**Arctic Grayling Recovery Program**
Principal investigator:	James Magee
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Additional investigators:	Scott Opitz

Objective: Research investigation of potential restoration sites for fluvial Arctic grayling and possible presence of Arctic grayling in some locations.

Findings: Investigated presence of Arctic grayling in the Gallatin River with the assistance of National Park Service personnel (Dan Mahony). We did not locate any grayling during survey in 1999.

FUNGI

Project title: **A Survey of *Pilobolus* from Yellowstone National Park**

Principal investigator: Dr. K. Michael Foos
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Additional investigators: Donald Ruch

Objective: 1) To obtain isolates of *Pilobolus* to examine for differences in DNA sequences and cellular short chain fatty acid composition. 2) To compare isolates from various locations by contrasting morphological characters to DNA sequences and short chain fatty acids. 3) To analyze and compare nucleic acid sequences in the various isolates to compare and contrast taxa. 4) To analyze and compare cellular short chain fatty acids in the various isolates to compare and contrast taxa. 5) To study the characteristics that can be used to identify isolates.

Findings: During 1999, isolates of *Pilobolus* were collected in Yellowstone National Park during July and October. These isolates were collected from mule deer, buffalo, pronghorn, and elk. They were collected from areas near Madison, Gibbon Meadows, Indian Creek, Canyon, Hayden Valley, and Mammoth Hot Springs.

All isolates have been maintained in the laboratory at Indiana University East and are being used as part of larger studies to distinguish among the species of *Pilobolus*. Collections of *Pilobolus* from this project are maintained at Indiana University East. It should be noted that isolates of *Pilobolus* do not survive well under cultivation. Most isolates of Pilobolus collected in earlier years have died.

Project title: **Fungi from Geothermal Soils and Thermotolerant Plants**

Principal investigator: Dr. Rusty Rodriguez
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Additional investigators: Regina Redman, Joan Henson, Kathy Sheehan

Objective: The proposed research will provide information to increase our understanding of fungal survival in unique environments, the roles of fungi in ecosystem dynamics, and the temporal and spatial scales of the micro-habitats that fungi occupy. Specifically, this work will provide information about: 1) how fungi survive under environmental conditions too harsh for mycelial growth; 2) if fungal community structure changes in response to environmental conditions; 3) if fungi can alter between saprophytic and symbiotic lifestyles in response to environmental conditions; 4) the scale of soil studies necessary to accurately assess the roles of these fungi in ecosystem dynamics; 5) how biological and/or genetic diversity of fungal communities changes in response to environmental conditions; and 6) the adaptive mechanisms of tolerance required for the growth of fungi soils containing high levels of metals and other inorganic chemicals. In addition, the feasibility of developing molecular biological tools will be determined for rapidly assessing a) fungal community structure based on molecular biomass measurements; b) the metabolically active and inactive species of fungal communities; and c) the occurrence of fungi in thermotolerant plants.

Findings: Several fungal species have been isolated from geothermal soils and found to be either mesophilic or thermophilic. The populations of both fluctuate throughout the year as a result of soil temperature and moisture. Fungi are in highest densities in soil under plants and can be found in soils with temperatures up to 100° C. The annual temperatures of the geothermal soils fluctuated as much as 30 – 40° C while non-thermal soils fluctuated 5 – 10° C There are two classes of fungi present in the soils: saprophytic and symbiotic. The symbiotic fungi colonize the dominant plant species in the geothermal soils (*Dichanthelium lanuginosum*). Preliminary data suggest that the fungal symbiont may be responsible for the ability of the plant to tolerate high temperatures, dry summers, and heavy metals. This project is still in progress.

Project title:	**Anti-Cancer Drug Discovery at Yellowstone National Park**
Principal investigator:	Dr. Philip Skehan
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Additional investigators:	Ignacio Chapela, Wade Davis, Hardy Wieting, Edgar Asebey

Objective: Discovery of new anti-cancer drugs from microscopic and near-microscopic fungi isolated from the park's extreme ecosystems.

Findings: The project has not yet started.

GEOLOGY

Project title:	**Environmental and Aquatic Chemistry and Biology**
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Additional investigators:	Roger Clark

Objective: Mobility of metals in natural waters associated with hot springs; lead in soils and trees along roadways; genetics of plants repopulating burn areas.

Findings: No samples collected in summer of 1999.

Project title:	**An Application of Oxygen Isotope Analysis to the Genesis of Yellowstone Volcanic Rocks**
Principal investigator:	Dr. Ilya Bindeman
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Additional investigators:	John W Valley, Mike Spicuzza

Objective: Meteoric water plays a crucial role in magma genesis of Yellowstone and similar volcanics from other areas. Oxygen isotopes provide a powerful tool in deciphering the role of meteoric water. New advances in the field of oxygen isotope analyses of minerals include laser ablation of refractory minerals that were not possible to analyze using conventional techniques. Among these minerals, zircon is particularly important due to the sluggish diffusion, resistance to hydrothermal alteration, and the ability to preserve magmatic oxygen isotope.

Findings: Both quartz and zircon from volcanic rocks of different ages were analyzed for oxygen isotope ratio using laser ablation at the University of Wisconsin stable isotope lab. We also used an ion microprobe at the University of Edinburgh (Scotland) to decipher very fine scale oxygen isotope zoning in zircons. Whole rock chemical analyses for major and trace elements were made and these were correlated with oxygen isotope data.

Preliminary results of the study show a clear temporal trend of oxygen isotope evolution in both quartz and zircon. The established pattern confirms the large scale involvement of meteoric water in magma genesis, especially after the Lava Creek Tuff eruption. We now are close to proposing a new model on the genesis of low-delta-18-O rhyolites of Yellowstone after major caldera collapses. Two papers have been written and they are now in review. Further work, however, is necessary to shed the light on the details of this process, especially if reviewers will ask us to analyze a few more units, or revisit old ones.

Project title: **Investigation of CO_2 Emissions Related to the Yellowstone Volcanic/Hydrothermal System**

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Additional investigators: Cindy Werner

Objective: 1) To estimate the CO_2 emissions due to the Yellowstone volcanic/hydrothermal system. 2) To monitor background temporal variability of CO_2 emissions and how variations are related to changes in hydothermal and seismic activity. 3) To study the spatial distribution of CO_2 emissions and investigate controls on spatial heterogeneity of gas emissions. 4) To monitor gas chemistry including carbon and helium isotopes to gain a broader understanding of the sources of magmatic gases and interactions with the hydrothermal system.

Findings: A stratified-adaptive sampling plan was designed to estimate CO_2 degassing in Yellowstone National Park, and applied in the Mud Volcano thermal area. The stratified-component focused effort in regions with the most spatial heterogeneity (high-flux regions), without biasing our estimate for the total region. The maximum and minimum measurements for vent and diffuse fluxes were 2.4×10^9 and 6.3×10^4 mols/yr, and 32,000 and 4.0 g/m^2/day, respectively. Fluxes observed in most vegetated regions of Mud Volcano were similar to values reported by agricultural studies (<38 g CO_2/m^{2}day). However, we also found a few high-flux vegetated sites (up to 5,000 g/m^2/day) that are likely thermal features that have waned in thermal activity, yet are preferred pathways for degassing of deep CO^2. Vent degassing (2.4×10^9 mols/yr) accounts for ~50% of the total degassing observed at Mud Volcano (4.9×10^9

mols/yr). Using estimates of magma emplacement rates from other studies, we calculated a rough CO_2 flux for the entire Yellowstone system based on the relationship between heat flux and CO_2 degassing. We approximated an emission rate of 7 x 10^{11} mols/yr, which is comparable to globally important volcanic fluxes.

Temporal variation of CO_2 emissions was observed to correlate with soil moisture, and environmental conditions. Preliminary investigation of the CO_2 emissions in the Upper Geyser Basin, Mammoth Springs, Roaring Mountain, Washburn Springs, Crater Hills, and the Lamar River Valley suggest that diffuse degassing is highest in acid-sulfate and travertine precipitating regions, and lowest in regions of silica precipitation and sulfur flows. No attempt has been made to estimate vent emissions in these areas.

Project title: **Geochemical and Isotopic Variations in the Absaroka Volcanic Supergroup – Implications on Petrogenesis and Magma Sources**

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Additional investigators: Jeffrey D. Keith, Eric H. Christiansen, Stephen T. Nelson

Objective: The formation of potassic magmas related to subduction has been studied in many areas of the world but remains controversial because of the high-K and relatively low SiO_2 compositions of the rocks. During the Eocene, the Farallon Plate was subducted beneath the North American Plate and is believed to have produced magmas that erupted throughout western North America. Some of these Eocene volcanic centers erupted distinctly potassic magmas, including the Highwood Mountains, Montana; Crazy Mountains, Montana; and Two Buttes, Colorado. The reason for the high K-content (and presumably other incompatible trace elements) is uncertain, but several possibilities exist. Lavas with high-K content have been interpreted to be related to deeper subduction. Others have suggested that these potassic magmas may have had a higher proportion from a phlogopite-bearing metasomatised lithospheric mantle source with lesser asthenospheric melts triggered by subduction-related fluids during the Eocene.

The eruptions of the Absaroka volcanic supergroup in Wyoming and Montana also occurred during the Eocene, producing both potassic and calc-alkaline flows. Documenting the textural and chemical variations in the volcanic rocks of a portion of the field in the Absaroka Mountains of northwest Wyoming provides information to develop a petrogenetic model for potassic magmas. Specific questions addressed by this research include: 1) What are the compositions of the magmas? How did they

vary in time and space? 2) How did the tectonic setting, magma sources, and magmatic processes affect the oxidation state of the magmas involved? 3) What were the sources of the magmas? What were the roles of the Farallon Plate that was subducted during the Eocene, ancient metasomatised mantle, or continental crustal contamination in these contrasting magma systems? 4) What role did crustal assimilation and magma mixing have in the development of the magmas? 5) How did the tectonic setting affect magma petrogenesis? 6) What new information about shoshonites can be obtained from the data?

Findings: Interpretation of chemical and isotopic (Sr and Nd) analyses of volcanic rocks in the Absaroka volcanic supergroup infer that variations in magma sources and evolutionary processes occurred for this volcanic suite. The Absaroka volcanic supergroup represents Tertiary eruptions associated with the subduction of the Farallon Plate below western North America. The mafic rocks are enriched in K and other lithophile elements. Extrusive and related intrusive rocks in the 49 to 44 Ma Absaroka volcanic supergroup are represented by the Washburn, Sunlight, and Thorofare Creek groups. This study focuses primarily on the Sunlight group from the central part of the field. The earliest flows of the Washburn and Sunlight groups were erupted in the northern and eastern portions of the volcanic field. The younger Thorofare Creek group was erupted in the southwestern portion of the volcanic field. The Sunlight Group contains a distinctive shoshonitic series and a contrasting calc-alkaline series.

Major and trace element abundances show that the magmas are not primary and that variations in the magma sources and magmatic processes occurred within each group. Magma mixing is indicated by disequilibrium textures such as resorption features and high concentrations of incompatible elements in intermediate composition rocks. The shoshonitic series is essentially tholeiitic (in terms of Fe/Mg ratios) and contrasts with the lower K and lower Fe/Mg ratios in the calc-alkaline magmas.

Important source components all of the magmas have high LILE/HFSE ratios. The enrichment of LILE may have been related to subduction contemporaneous with magma formation, or it may have been the result of subduction processes during the Archean when the basement formed. Evidence for both processes is present in the Absaroka volcanic supergroup. The isotopic signatures of Sr and Nd in Sunlight group flows and dikes suggest a mixing of magmas from ancient phlogopite bearing lithospheric mantle (such as the base of the Wyoming Craton) and asthenospheric sources. The flows of the Washburn and Thorofare Creek Groups have higher initial $^{87}Sr/^{86}Sr$ values, which are interpreted to be from assimilation of crustal material, but eNd values are still negative, suggesting that contributions of lithospheric mantle with asthenospheric mantle were also important.

Modeling of shoshonitc melts infer that orthopyroxene fractionation at high pressures did not produce the K enrichment characteristic of shoshonites. The calc-alkaline series identified in the Absaroka volcanic supergroup did not evolve from the shoshonitic magmas, but may have had common source components. The plagioclase + clinopyroxene + olivine + magnetite ± apatite assemblage observed in the shoshonitic samples indicates low pressure crystallization of a magma with a high initial K content.

Project title: **The Search for Microbial Biomarkers in Terrestrial Deposits**

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Additional investigators: Sean Guidry

Objective: The primary purpose of this investigation is to evaluate the fossilization process and the potential for a long term record of the microbial life that exists associated with hot springs and their carbonate (travertine) and siliceous (siliceous sinter) deposits. Basically, we are looking for biomarkers, indicators that microbes once existed as part of the hot spring environment. This will allow us to determine the likelihood of finding fossilized microbes in extraterrestrial bodies (e.g., Mars) and what is the most likely preserved material. For example, will we have a better chance of finding body fossils or geochemical indicators of former organisms? In order to carry out this investigation, we have and will continue to analyze the waters from which the minerals precipitates originate as well as the precipitates of carbonate (Mammoth Hot Springs) and siliceous sinter (Cistern Spring, Norris Geyser Basin). It is our intent to search for mineralogical (crystal habit, size, etc.) and geochemical (major, minor, and trace elements as well as isotopic) differences between biotically induced and abiotic precipitates as well as microbial remains (bacterial body fossils, biofilms, etc.).

Findings: Our work to date has indicated that biogenic compounds appear to breakdown relatively quickly in this hot environment and thus will not be well preserved in the ancient record. Some body fossil types, however, seem to display relatively good preservation potential. Samples are being curated in our department collections. Descriptions of the samples in the collection were previously forwarded.

Project title: **Geochemical Baselines in the Greater Yellowstone Area**

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Additional investigators: Daniel R. Norton, William Miller, Harley King, Richard Sanzolone

Objective: 1) Provide objective, unbiased geochemical baseline data for about 50 chemical elements determined in samples of rock, active stream-sediment, water, plants, and animal scat collected from

scattered localities throughout Yellowstone National Park and the adjacent U.S. Forest Service lands. Baselines to include raw data and interpretive reports. 2) Identify the sources, such as geothermal features, past mining, and recreation, of anomalous concentrations of selected elements. 3) Determine the chemistry of selected elements in the food chain and how these elements may impact the health of wildlife in the park.

Findings: Samples of stream sediment, rock, water, and/or animal scat have been collected from as many as 555 sites in and around YNP. These samples have been analyzed for as many as 50 elements. In the northeastern part of the park, weakly anomalous levels of elements related to mineralized rock or to past mining in the Cooke City area have been detected in samples from the Soda Butte Creek drainage basin. These weak anomalies extend to the confluence of Soda Butte Creek with the Lamar River, where sediments from that stream with background levels dilute the anomalous concentrations from Soda Butte Creek to background levels.

In the geothermal areas of the park studied to date (both fossil and active), a common suite of elements is generally present in sediment downstream from each area. Concentrations for some elements, such as arsenic and fluorine, are significantly elevated as compared to background element levels. Cesium seems to be the best unique indicator of geothermal activity.

Analysis of 62 samples of elk or bison scat shows anomalous concentrations of elements associated with geothermal features for those animals grazing near such features, indicating that animals browsing in geothermal areas are ingesting significant levels of elements such as arsenic and fluorine. The effect of fluorine on elk and bison has been documented by others. The effects of other elements on elk or other animals is not known. Sampling is continuing to better define and understand the sources of anomalies and the possible impacts of various elements on park animals.

Project title:	**Volcanology and Petrology of the Yellowstone Plateau Volcanic Field**
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Additional investigators:	Wes Hildreth

Objective: To understand the origins and eruptive mechanisms of late Cenozoic volcanic activity in the region of Yellowstone National Park and to complete systematic geologic-mapping studies carried out intermittently in the park region since the 1960s.

Findings: No new work was done on this project in 1999. USGS Professional Paper 729-G is now nearly ready for publication by the USGS Western Publications Group, but still awaits final digital details on the largest geologic-map plates.

Project title:	**Geochemistry and Geochronology of Eocene Potassic Volcanism in the Absaroka Volcanic Field**
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Additional investigators:	Charles Lindsay, Julie Hamblock

Objective: Our objective is to carry out a geological and geochemical transect across the northern part of the Eocene Absaroka volcanic field. Because the Absaroka volcanic rocks record one of the most voluminous and compositionally diverse magmatic episodes to affect the Cordillera during the Eocene, the results obtained from this study will improve our knowledge of the ages, compositions, and petrogenesis of Tertiary magmatism in the northern Rocky Mountains. This, in turn, will provide insight into the fundamental problem of how rock suites with arc-like geochemical features can form in such different tectonic environments and possibly in the absence of contemporaneous subduction. The targeted areas in Yellowstone National Park are the Mt. Washburn-Observation Peak volcanic center, the Sepulcher Mountain-Electric Peak eruptive center, and the Sylvan Pass-Eagle Peak eruptive center.

Findings: Our work in the Washburn Range during the previous year is summarized as follows. Volcanic rocks in the southwest Washburn Range erupted on the flank of the Mount Washburn volcano; a major Eocene (~54-52 Ma) eruptive center in the western calc-alkaline belt of the AVP. Rocks examined are crudely bimodal, including ol+cpx basaltic andesites and mafic andesites (52-58 wt% SiO_2) and amph (±bio) dacites (63-67 wt% SiO_2); intermediate compositions are rare. Silicic rocks are restricted to low stratigraphic levels, whereas mafic magmas are present at higher levels. These relationships contrast with those at Mount Washburn proper, the central edifice of the Washburn volcano, where 2-pyx andesites dominate and fill the gap in the southwest Washburn Range suite. For the volcanic system as a whole, major element compositions demonstrate that the rocks represent a true "calc-alkalic" suite (Peacock index ~ 60).

The mafic andesitic magmas were generated from basaltic andesitic parent magmas by varying degrees of mixing with silicic melts derived by crustal anatexis plus small degrees of fractional crystallization. Incompatible trace-element contents are elevated (Rb = 24-64 ppm; Ba = 590-1550 ppm) and define linear trends on SiO_2 variation diagrams. Compatible trace elements are also elevated (Ni = 134-14 ppm; Cr = 422-33 ppm), but trends are more diffuse than for incompatible elements. Chemical models

require fractionation of minor amounts (<5%) of olivine and clinopyroxene in mafic magmas prior to or during mixing. Cross-over patterns on chondrite normalized REE diagrams (La/Yb n = 5-17) support the mixing model and, along with increasing Sr/Y with decreasing Y, suggest the silicic melts were produced at deep crustal levels where garnet was stable.

The field and geochemical relationships suggest initial development of small silicic magma bodies beneath the Washburn region due to intrusion of basalt into the lower continental crust. With time, magma supply rates probably increased and became more focused beneath the core of the Washburn volcano, developing a zone of large-scale mixing. On the periphery of the system, magma supply rates were probably lower, allowing fractionated mafic magmas to ascend and interact less with silicic magmas.

Project title: **Aqueous-Solid Geochemical Process Model of Travertine Precipitation at Angel Terrace, Mammoth Hot Springs**

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Additional investigators: George Bonheyo, Craig Bethke

Objective: This research will develop a conceptual and quantitative model that identifies the abiotic and biotic processes controlling the deposition of travertines at Angel Terrace, Mammoth Hot Springs. Travertines form where carbonate minerals precipitate near the vents of terrestrial hot springs, and they record important information on water chemistry, hydrologic transport, climate, and microbial populations. There are, however, no systematic studies that offer guidance on how to interpret the complex crystalline fabrics and chemistries inherent to hot spring travertines. The process model developed in this proposal will considerably improve our ability to extract environmental information from ancient travertines by directly linking crystalline fabric and chemistry to aqueous processes within an environmental framework.

Findings: Petrographic and geochemical analyses of travertine-depositing hot springs at Angel Terrace have been used to define five depositional facies along the spring drainage system. Spring waters are expelled in the vent facies at 71 to 73° C and precipitate mounded travertine composed of aragonite needle botryoids. The apron and channel facies (43-72° C) is floored by hollow tubes composed of aragonite needle botryoids that encrust sulfide-oxidizing *Aquificales* bacteria. The travertine of the pond facies (30-62° C) varies in composition from aragonite needle shrubs formed at higher temperatures to ridged networks of calcite and aragonite at lower temperatures. Calcite "ice sheets", calcified bubbles,

and aggregates of aragonite needles ("fuzzy dumbbells") precipitate at the air-water interface and settle to pond floors. The proximal-slope facies (28-54° C), which forms the margins of terracette pools, is composed of arcuate aragonite needle shrubs that create small micro-terracettes on the steep slope face. Finally, the distal-slope facies (28-30° C) is composed of calcite spherules and calcite "feather" crystals.

Despite the presence of abundant microbial mat communities and their observed role in providing substrates for mineralization, the compositions of spring-water and travertine predominantly reflect abiotic physical and chemical processes. Vigorous CO_2 degassing causes a +2 unit increase in spring water pH, as well as Rayleigh-type covariations between the concentration of dissolved inorganic carbon and corresponding $d^{13}C$. Travertine $d^{13}C$ and $d^{18}O$ are nearly equivalent to aragonite and calcite equilibrium values calculated from spring water in the higher-temperature (~ 50-73° C) depositional facies. Conversely, travertine precipitating in the lower-temperature (< ~ 50° C) depositional facies exhibits $d^{13}C$ and $d^{18}O$ values that are as much as 4 less than predicted equilibrium values. This isotopic shift may record microbial respiration as well as downstream transport of travertine crystals. Despite the production of H_2S and the abundance of sulfide-oxidizing microbes, preliminary $d^{34}S$ data do not uniquely define the microbial metabolic pathways present in the spring system. This suggests that the high extent of CO_2 degassing and large open-system solute reservoir in these thermal systems overwhelm biological controls on travertine crystal chemistry.

Microbes and biofilms are entombed within the Angel Terrace travertine. Preliminary results reveal that both modern and ancient travertine contains abundant microbial organic matter entombed between crystals and in fluid inclusions. Comparison of microbial composition and crystal chemistry are being made between the modern and ancient travertine at Mammoth Hot Springs (0 to ~8,000 ybp) with the intent of defining fossilization potential. The identity of the travertine microbes is being approached using microscopy and 16S rRNA gene sequencing. Travertine samples collected for this study are being reposited in the research collection of the Department of Geology at the University of Illinois Urbana-Champaign.

Project title:	**Geochemistry of Hot Spring Sinters and Microbial Mats**
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Additional investigators:	Cindy Wilson, Bill Cooper

Objective: 1) Investigate geochemical variations in microbial mats, pore waters, siliceous sinters, and geyserites at different hot springs and thermal drainages in the park. Results will be compared with stage of silica diagenesis and geochemistry. 2) Investigate the local hydrogeological characteristics of hot spring-influenced drainages. Results will be used to calculate mass balances for such drainages, to

determine silica deposition rates in sinter mounds and to determine interaction with local groundwater. 3) Investigate photochemical processes in thermal springs of various composition.

Findings: Photochemical studies on the production of hydrogen peroxide and the redox cycling of iron continued this year. Field studies with Dr. Lynn Rothschild were conducted in July. A field reconnaissance of sites with new collaborator, Dr. Bill Cooper was conducted in September.

Research efforts focused on determining chemical characteristics that control the production of hydrogen peroxide in thermal springs. Absorbance is a critical process in any photochemical reaction. The absorbance spectra of hot spring waters, treated in various ways, were collected. Absorbtivity (abs/cm) were calculated from the absorbance spectra. The values were lower than for other surface waters. The absorbtivity is used to calculate the quantum yield for a given reaction. Calculations of the quantum yield for hydrogen peroxide in thermal waters indicate that the number of moles of hydrogen peroxide produced per mole of photons absorbed is five to ten times higher in these thermal waters than other surface waters. This is an important finding because it suggests that hydrogen peroxide can be produced in significant quantities although the waters are fairly nonabsorbent. Light is not greatly attenuated with depth, thus there is potential for hydrogen peroxide to form over several meters depth. As a consequence, the environment of thermal springs may be harsher than previously thought.

Studies were conducted on the distribution of aluminum in siliceous sinters from Pott's Basin and Excelsior Crater, Midway Geyser Basin. As a trace constituent, its distribution is controlled by changes in fluid composition along a flow path. Preliminary results suggest that precipitated aluminum is concentrated in the interiors of microbial filamental fragments in some thermal springs but not others.

Project title: **Digital Quaternary Map of Wyoming including Yellowstone**

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Objective: Field checking of Quaternary stratigraphic sites was conducted as part of the University of Wyoming's Summer Research Apprentice Program. In Yellowstone National Park, the University of Wyoming team examined deposits and logged digital coordinates of 44 Quaternary stratigraphic sites. The YNP stratigraphic sites in the Canyon area and along the north and west shores of Yellowstone Lake are part of a digital data layer for a Quaternary geologic map of Wyoming.

More than 70 stratigraphic sites exist statewide. In addition to the digital map and Quaternary stratigraphic sites, information about Quaternary faulting, sediment descriptions, geochemistry of volcanic ashes, locations of relict periglacial wedges, a correlation chart, and bibliography are being compiled

from previously published maps, field guides, and scientific publications. The digital Quaternary geologic map of Wyoming will be a one-stop source of information available on the Wyoming Internet Map Server (*http://wims.sdvc.uwyo.edu*). The preliminary digital Quaternary geologic map of the entire state of Wyoming (including Yellowstone) will be available for viewing later this year.

Findings: Forty-four Quaternary stratigraphic sites in Yellowstone were examined for the Yellowstone portion of the digital Quaternary geologic map of Wyoming. Quaternary stratigraphic sites were visited in the Grand Canyon of the Yellowstone, Hayden Valley, and along the west and north shores of Yellowstone Lake. The purpose of this reconnaissance was 1) to field check the Yellowstone map units; 2) to obtain GPS locations of important Quaternary stratigraphic sites using a Trimble Pro XRS receiver; and 3) to examine various Quaternary sediments for map units descriptions.

On the north shore of Yellowstone Lake, volcanic ash was collected from two locations: Fishing Bridge; and Indian Pond. Samples were prepared for geochemical analysis according to the techniques described by Sarna-Wojcikcki and others (1984). After dry sieving, chemical preparation, and magnetic separation, the Fishing Bridge ash was primarily glass shards. The Indian Pond ash still requires the use of heavy liquids to further concentrate the glass shards. The Fishing Bridge geochemistry (weight %) shows an Fe_2O_3/CaO ratio that is consistent with known G-type rhyolitic glasses. Fe/Ca ratios of Yellowstone-source ashes fall within the G-type rhyolitic field on an Fe-Ca plot. The Indian Pond ash is a non-Yellowstone volcanic ash. Further laboratory and geochemical work is needed on the Indian Pond volcanic ash and samples of Yellowstone volcanic ashes found in Quaternary deposits throughout Wyoming.

Project title: **The Structure, Facies, and Deposition of Siliceous Sinter around Thermal Springs: Implications for the Recognition of Early Life on Earth and Mars**

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Objective: 1) To study the textures and structuring of siliceous sinters deposited around hot springs and to determine the physical and chemical controls on sinter deposition. 2) To characterize the role of thermophilic organisms in sinter deposition. 3) To compare the structure of sinter with that of putative biological structures in the oldest sedimentary rocks on Earth. 4) To evaluate which features of sinter are diagnostic of biological influences to aid in possible identification of organisms during planetary exploration.

Findings: Our investigations to date have focused on the hydrodynamic controls on the structuring and

morphology of siliceous sinter facies around alkaline hot springs and geysers in Yellowstone. Our work can be divided into two sub-studies: 1) an investigation of low-temperature (less than 73° C) sinter facies, where cyanobacterial mats play a significant role in the structuring and development of sinter at all observational levels; and 2) an investigation of high-temperature (greater than 73° C) sinter facies where thermophilic bacteria may play a role in mediating silica precipitation rates and influence microstructuring and microtextures, but where hydrodynamics are the primary control on the development of sinter macrostructures. Ph.D. student Deena Braunstein completed her Ph.D. study of high-temperature sinter in Yellowstone and graduated from Stanford in June 1999. Her thesis includes three chapters dealing with: 1) the hydrodynamic behavior and structuring and morphology of siliceous sinter deposited around a variety of alkaline siliceous hot springs and geysers; 2) the microscopic structuring and deposition of siliceous sinter; and 3) a case study of sinter deposited around Coral Pool (Shoshone Geyser Basin). Dr. Lowe visited YNP in September 1999 and continued his investigations at Steep Cone Spring, which has been a site of detailed photo-documentation of sinter growth rates for several years. In addition, growth-rate experiments were at the Buffalo Pool Group, Five Sisters Springs, and Fountain Paint Pots area.

The principal activities for 1999 consisted of monitoring sinter growth-rate experiments at Steep Cone Spring, Fountain Paint Pots area, Buffalo Pool Group, and the Five Sisters Group. Additional experiments installed at Coral Pool in Shoshone Geyser Basin in 1998 were left intact and not visited in 1999. These experiments are part of a long-term study of sinter growth rates.

Project title:	**Mine Impacts on Stream Morphology, Microhabitats, and Riparian Ecology**
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Additional investigators:	Robert Ahl, Ed Schrader, Jamie Harris

Objective: The objective of this research is to determine the distribution of metals from mining in sediments of a riparian system, investigate the processes controlling those distributions, and determine the biotic impacts associated with the metals. The investigation focuses in Soda Butte Creek, which experienced mining in its headwaters up until 1953.

Findings: Mine-derived metals in sediments of the active channel display a decrease in the downstream direction due to dilution by cleaner sediments from tributaries. Recent floods in Soda Butte Creek have not cleaned the system because exposed mine waste is washed into the creek at the same rate as clean sediments, leading to no net decrease in metal concentrations. Metals in the bed sediments are depress-

ing macroinvertebrate populations. Metals in floodplain soils are reducing grass biodiversity, biomass, and density. Ongoing studies will monitor heavy metal levels and macroinvertebrate populations to determine long-term changes and recovery of the system.

Project title:	**Volcano Emissions**
Principal investigator:	Kenneth McGee
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Additional investigators:	Terrence Gerlach, Michael Doukas, Richard Kessler

Objective: Survey and characterize carbon dioxide emissions from Yellowstone soils and thermal areas in order to identify possible areas of anomalous degassing from depth and to provide a baseline with which to compare future surveys of carbon dioxide in the event of volcanic unrest. The study involves airborne measurements of carbon dioxide and other gases in the air above the park as well as ground measurements of carbon dioxide soil efflux within the park.

Findings: Several areas of carbon dioxide efflux have been measured within the park that are greater than what would be expected from normal biologic activity in the soil. In addition, several carbon dioxide plumes from various sources within the park were successfully measured in the air above the park in 1998 and 1999 utilizing sensitive instrumentation mounted in fixed-wing aircraft. Similar measurements utilizing helicopters as the airborne platform are anticipated. The detailed analysis of data is not yet complete.

Project title:	**Holocene and Modern Geomorphic Response to Fires, Floods, and Climate Change in Yellowstone National Park – Natural and Anthropogenic Influences on Stream Systems**
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Additional investigators:	Paula M. Watt

Objective: To provide a long-term perspective on the geomorphic impacts of the 1988 Yellowstone fires, we are investigating Holocene sedimentation in northeast Yellowstone using post-1988 fire-related events as a guide for interpretation of alluvial fan stratigraphy. Comparison of the timing of fire-related events with climate proxy records elucidates the relative controls of climate, fire, and intrinsic geomorphic thresholds on alluvial systems. We are also documenting extreme floods of the last ~300 years and their effects on valley floor landscapes of northeast Yellowstone. Recent changes in stream channels seen through analysis of air photos, historical photos, and re-surveying are evaluated in the context of flood history, riparian vegetation and ungulate browsing, and intrinsic characteristics of basins and channels. We are also studying a 1950 dam failure at Cooke City, Montana, that deposited acidic, metal-rich mine tailings along the Soda Butte Creek floodplain.

Findings: Our study of the geomorphic response to fires is largely complete, and shows that fire is both an important catalyst for landscape change and is strongly controlled by climate on 100-1000 year time scales. Ongoing study has identified major floods in the Lamar River system in 1918, the early 1870s, and possibly near 1800. These floods had much greater peak discharge than the 1996 and 1997 floods (the largest in gauge records), and their extensive dry gravelly deposits have lasting impacts on stream channels and valley floor ecosystems. The 1950 tailings dam break produced extreme discharges but had short duration, and thus caused little erosion. However, tailings deposits along Soda Butte Creek have significant copper and lead content, impact floodplain vegetation, and continue to be eroded into the channel, adding to mining-related metal pollution.

Project title: **Redox Processes Controlling Arsenic Mobility in the Hyporheic Zone**

Principal investigator: Dr. Johnnie Moore
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Objective: To determine the role that the hyporheic zone (the zone just beneath the bed in a stream) plays in mobilizing arsenic from sediments enriched in arsenic.

Findings: Unfortunately, we were not able to conduct research on this project because none of our funding sources came through. We did no sampling and no work of any kind in the park during 1999.

Project title: **Sulfur Speciation and Redox Processes in Mineral Springs and their Drainages**

Principal investigator: Dr. Kirk Nordstrom
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Additional investigators: Martin Schoonen, Gordon Southam

Objective: The primary objectives are to determine the actual speciation of dissolved sulfur species as they undergo oxidation and volatile losses for H_2S, and to study the evolution of acidic drainages unaffected by pyrite oxidation. Intermediate sulfoxy anions such as thiosulfate have been implicated as complexing agents to solubilize and mobilize metals in the formation of ore deposits and as monitors of volcanic activity. We hope to relate sulfur speciation in hot springs and their overflow drainages to rates of oxygen diffusion and solubility. We also hope to learn how the chemistry of acidic drainages dominated by elemental sulfur oxidation differs from those dominated by pyrite oxidation.

Findings: Two USGS open-file reports containing analyses of 99 hot spring, geyser, and surface water samples from 1974-75 sampling and 42 samples from 1994-95 sampling have been published in 1998 and are available for free from the senior investigator. A report on water analyses collected during 1996-98 will be available later this year. A scientific paper summarizing the occurrence and interpretation of thiosulfate in Yellowstone waters has been published and a detailed study of the formation and decomposition of sulfur species in Cinder Pool is in press. During the 1999 field season, 30 water samples were collected from Norris Geyser Basin and six samples from Brimstone Basin. Sampling and on-site analysis was made possible with a mobile laboratory equipped with an ion chromatograph, a portable UV-visible spectrophotometer, and an autotitrator. New hot springs suddenly appeared in the Ragged Hills area of Norris in late spring/early summer of 1999 and these were sampled for all major ions and most trace elements in September. In addition, all the samples from Norris were analyzed for arsenic redox species, i.e., As(III/V). The preliminary and unexpected results indicate that all samples have some As(V), the amount of As(V) seems to correlate with the amount of exposure to air or oxygenated groundwaters, and surface drainages from hot springs are mostly oxidized to As(V). This rapid oxidation is presumed to be caused by microbial catalysis and *Thiobacillus thiooxidans* has been identified in these waters.

Project title:	**Quaternary Geology, Geo-Ecology, Geoarcheology, Neotectonics, and Hazards Studies of the Greater Yellowstone Area**
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Additional investigators:	Ken Cannon, Lisa Morgan, Don Despain, Pat Shanks

Objective: 1) Investigate Yellowstone Lake and river level changes associated with caldera inflation/subsidence cycles. 2) Geoarcheology of sites, particularly around Yellowstone Lake. 3.) Hazards appraisal, particularly late Quaternary faulting, hydrothermal explosions, volcanism, and landsliding. 4) Outreach, including books, training videos, and high quality videos on Yellowstone geology. 5) Relationships between geology and ecology, particularly the meadow-forest contrast. 6) Investigate Crevice Lake as a coring site and develop proposals for coring and developing information from cores. 7) Investigate and write up relations between Yellowstone hotspot and associated volcanism, faulting, and uplift and broad scale ecological relations in the Greater Yellowstone Area.

Findings: Rhyolitic hotspot volcanism constructed the Pleistocene Yellowstone Plateau. Streams eroding the steep edges of this plateau form scenic canyons and waterfalls. Rhyolite is poor in nutrients and forms sandy, well-drained soils that support the monotonous, fire-prone, lodgepole pine forest of the Yellowstone Plateau that contrasts with the more varied vegetation, including spruce-fir and whitebark pine forests broken by grassy meadows on the bedrock and surficial materials that flank this plateau. Upwelling waters heated by hotspot magmas drive Yellowstone's famed geysers, hot springs, and mudpots, which provide habitat for specialized, primitive ecosystems of algae and bacteria.

Basin-and-range faulting has accompanied migration of the hotspot to Yellowstone, forming linear ranges and valleys on both sides of the hotspot track of the eastern Snake River Plain. Hotspot-associated faulting forms a distinctive part of the GYE, with characteristic rugged, forested ranges and adjacent flat-floored grassy valleys. The contrast in altitude from the basins up through the adjacent ranges is important to the ecosystem and provides a year-round environment for various and cyclic annual migration paths and seasonal upward migration in maturation of vegetation. The valleys provide natural meadows, agricultural land, town sites, and corridors for roads.

Recent uplift to form the Yellowstone crescent of high terrain has also resulted in ongoing erosion of deep, steep-walled valleys in readily erodible rock. Modern and Pleistocene weather and resultant vegetation patterns strongly relate to crescent of high terrain and the of the Snake-River-Plain track. Moist Pacific air masses traverse the Snake River Plain and rise onto the Yellowstone Plateau and then

the crescent of high terrain and produce deep orographic snows, and east of the mountains, a precipitation shadow. Such deep orographic snows nourished extensive Pleistocene glaciers that covered the core GYE and produced many of the landscape features on which modern soils have formed, including gravelly outwash plains covered with sagebrush-grassland and silty lake sediments commonly covered by lush grassland such as Hayden Valley.

Human settlement and use of the GYE reflects the hotspot processes of uplift, volcanism, and faulting. Uplift formed a remote highland from which streams drain radially outward like spokes from a hub. Along these radial drainages humans have settled around Yellowstone, established roads, irrigation systems, and political associations. Decision making involving the GYE is complicated by multiple jurisdictions athwart this hotspot highland, including 18 counties, seven national forests, three states, and two national parks.

In 1999, I prepared a field guide and co-led with Don Despain an interdisciplinary field trip through different habitat areas of Yellowstone. Many relations between surficial geology, soils, and vegetation were discussed. Although much of Yellowstone is forested, a strong correlation exists between fine-grained surficial materials and meadows, which are one of the most important features in Yellowstone's ecology. The critical factor appears to be fine-grained soil matrix holding most snowmelt water at shallow depths, thus favoring herbaceous vegetation.

Project title:	**Operation and Development of an Earthquake and Volcano Information System at Yellowstone (YSGN) and Ancillary Research on the Geodynamics of the Yellowstone Hotspot**
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Additional investigators:	Charles Meertens

Objective: The primary objective of the Yellowstone earthquake and volcano information system is to operate the Yellowstone seismic and GPS networks (YSGN) necessary to monitor seismicity and ground deformation that may be related to both volcanic and tectonic earthquake activity. In addition, ancillary research funded by the National Science Foundation titled "Geodynamics of the Yellowstone hotspot" use the data and support in part the student and faculty research described herein. The data acquisition component of our project include maintenance, recording, routine analyses and installation of seismic and GPS instruments in and around Yellowstone National Park. Data from the YSGN provide information for public safety, NPS management and planning, access of GPS information for surveying

purposes, and access to interpretation of our data for scientific research. The YSGN is designed to monitor earthquakes of the entire Yellowstone volcanic system, including Yellowstone National Park and the nearby Hebgen Lake fault zone. The GPS stations provide continuous monitoring of the crystal deformation of the volcanically active Yellowstone caldera and surrounding areas. The GPS data are accessed routinely for use as base stations for park surveying needs. This integrated monitoring system provides real-time earthquake surveillance by a modern 22-station, 32-component, seismic network telemetered via FAA microwave links (at no cost to the project) to Salt Lake City, and digitally recorded at the University of Utah Seismograph Stations. The seismic data are accessible via the Internet from the University of Utah. Continuous GPS data are recorded at five sites (two stations are cooperatively operated with the USGS) and are processed at the University of Utah. The GPS data are archived at UNAVCO and accessible via the Internet. The USGS Volcano Hazards Program primarily funds this cooperative project with additional support form the National Park Service for fieldwork. The primary products for this project are earthquake catalogs, online availability of continuos GPS data, the services of a regional earthquake and GPS recording and information center, and timely release of unusual earthquake activity reports to the USGS and the NPS.

Findings: In addition to routine network operations, notable efforts during the report period included continued upgrading and maintenance of seismograph and GPS stations against the harsh winter conditions of Yellowstone. The tasks included: 1) continued installation of audio bandpass filters at relay sites to reduce interference; 2) replacement of aging radio transmitters and receivers throughout the network; 3) VCO system repairs and upgrades; 4) removing a seismic station PITT near Lake and relocating it to a site in an old gravel pit near Little West Thumb Creek; 5) upgrading the Norris station with broadband seismometers; and 6) installation of three dual-frequency GPS sites. Nineteen of the twenty-two stations of the Yellowstone seismograph network were visited for maintenance during the report period. The digital broadband seismograph station near the Madison Canyon has had long-term telemetry problems requiring several visits to the site. After a long process of elimination we found out that U.S. West telephone line had excessive noise. This was corrected and the station is working fine. Removed the broadband seismometers from Lake Butte and installed them at Norris for better geographic coverage of the caldera. Assisted the USGS-NEIC with maintenance of a cooperative U.S. National Seismograph Station (USNSN) located near Yellowstone Lake (LKWY). Sawelle Peak Repeater site - Made repairs to antennas damaged by winter and ice from 98-99 winter. Maintenance of the continuous recording, high-precision GPS station Lake and Mammoth. Installation of three continuously recording GPS receivers at Old Faithful, Hayden Valley, and White Lake. These stations along with two other stations provide much needed monitoring of ground motion of the YNP caldera. Data are automatically retrieved via satellite and dial-up telephone lines every 24 hours and then incorporated into the UNAVCO GPS archives. Analysis continued on the systematic determination of local magnitudes (M L) and M L station corrections using local USNSN, Montana Wood-Anderson station BUT and Utah broadband stations, for all coda magnitude (M C) 3.0 and greater earthquakes located in the Yellowstone region since January 1, 1994. Steps towards submitting 19 years of University of Utah short-period waveform data to the IRIS Data Management Center in SEED format, including: 1) use of IRIS's PDCC (Portable Data Collection Center) software; 2) compilation of a database inventory of instrument components for all stations in our network since digital recording began in 1981; and 3) compilation of system response information for all past and present stations in our network. Continued

software development to integrate new digital data streams (REF, TEK, and USNSN) with existing analog data streams for routine analysis. Completion of a network inventory for the CNSS (see *www.cnss.org/NETS*) and major progress towards a comprehensive station inventory for the IASPEI handbook. Submission several times per day of earthquake catalog data for the Utah region to the Council of the National Seismic System's (CNSS) composite catalog. Assistance to the National Park Service with long-term plans for implementing volcano and earthquake hazard assessment and identifying manpower needs. Analysis of space-time variations of seismic source mechanisms and related stresses of Yellowstone reported in an M.S. thesis of Greg Waite. Discussions with the USGS, Menlo Park volcano seismology group regarding implementation of long-period event detection software (within Earthworm). Analysis of ground deformation of the caldera using GPS and its relation to faulting and earthquakes of the nearby Hebgen Lake fault zone reported in a M.S. thesis of Christine Puskas. Fabrication and design of particular items for all the above activities in our University of Utah electronic shop. Presentation of the findings and objectives of our research to as well as presentation of new information contained in the recent book *Windows into the Earth, The Geologic Story of Yellowstone and Grand Teton National Parks* By Robert B. Smith and Lee J. Siegel to NPS personnel.

Availability of data: All seismic waveform data archived by the University of Utah Seismograph Stations are available upon request (typically delivered to the user in SAC ASCII or binary format). Earthquake catalog data for the Utah region are available via anonymous ftp, *ftp.seis.utah.edu: pub/UUSS_catalogs*, or by e-mail request to: *request-quake@eqinfo.seis.utah.edu*, or via the Council of the National Seismic System's composite earthquake catalog, *http://quake.geo.berkeley.edu/cnss*. See also the University of Utah Seismograph Stations homepage at *www.seis.utah.edu*. GPS data are available through the Unavco GPS data archive site at: *http://archive.unavco.ucar.edu/cgi-bin/dmg/pss*. The contact persons for data requests are Susan J. Nava, Network Manager, e-mail: *nava@seis.utah.edu* or Dr. Robert Smith, e-mail: *rbsmith@mines.utah.edu*.

Project title:	**Ground Penetrating Radar Studies at Mammoth Hot Springs**
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Additional investigators:	Laura Joss, William Sill

Objective: The purpose of this study was to identify possible geologic risks involved in future construction near Mammoth Hot Springs, Yellowstone National Park. Ground penetrating radar was used to help identify these geologic hazards.

Findings: In the Mammoth Hot Springs area of Yellowstone National Park, the surface rock is predominantly a hydrothermal variety of layered, porous limestone known as travertine. Limestone typically has low electrical conductivity making it ideal for ground penetrating radar (GPR) use. In the spring of 1997, GPR tests were conducted in three areas: 1) near the 1895 mail carrier's cabin; 2) near the Ice House; and 3) Opal Terrace. At the time, the first two sites were considered as possible locations for the Yellowstone Heritage and Research Center, while the third site was investigated because of concerns about the encroachment of Opal Terrace on the Executive House. Based on the success of these initial tests, a more detailed study was conducted at a two-acre area surrounding the mail carrier's cabin.

In these studies, penetration depths of over eighteen meters were observed in some of the GPR profiles. The profiles show: 1) buried utilities; 2) numerous, relatively continuous, travertine layers; and 3) possible cavities. A rapid loss in signal strength is observed at the bottom of most of these profiles. This lack of returning reflected energy at the base of the highly-reflective layered travertine package could be caused by the boundary between travertine and less reflective, more conductive, volcanic or sedimentary rocks that are likely found underneath the travertine in the area. Alternatively, the rapid loss in signal strength could be caused by a relatively high electrical conductivity that would be expected in rock saturated with mineralized water. GPR successfully imaged travertine layers in the Mammoth Hot Springs area and detected a possible subsurface cavity near the historic Executive House. GPR shows tremendous potential as a technique for evaluating the subsurface near thermal features throughout Yellowstone. These results were presented at the Sixth Yellowstone Interagency Science Conference held at Mammoth, Wyoming, September 16-17, 1999. No additional data were collected in 1999.

Project title:	**Eruption History of the Sepulcher Formation as Determined by Geochemistry**
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Additional investigators:	Harold Coffin

Objective: To use the geochemical analyses and statistical methods in the analysis of the breccia, rock, and ash samples from Yellowstone fossil forest located in the Specimen Creek area in an attempt to clarify the origin and history of the breccia flows, ash stringers, and the petrified trees that are located within these flows.

Findings: During 1999 three days were spent in the field verifying major fossil locations by GPS. No samples were taken during this time. Statistical analyses are almost complete for the entire area. Manu-

script preparation is in progress.

Project title:	**Tracing Fine Sediment Transport in Fluvial Systems Using Fallout Radionuclides**
Principal investigator:	Dr. Peter Whiting
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Additional investigators:	Gerald Matisoff

Objective: Our objective is to investigate the erosion mechanisms of fine sediment and the transport characteristics of fine sediment in channels. Specifically, we aim to answer questions on the source and transport of fine sediment in the Yellowstone River drainage. We employ fallout radionuclides (^{7}Be, ^{137}Cs, ^{210}Pb) as tracers. ^{7}Be has a short half-life (53 days) which provides a marker for sediment recently delivered from the landscape. By monitoring stream sediment for the amount of ^{7}Be and other radionuclides, we can evaluate the fraction of sediment that has been recently delivered from the landscape as opposed to eroded from the stream bed, estimate transport distances for the fine sediment, and estimate residence times for sediment and adsorbed materials.

Findings: Our findings after one week of reconnaissance and analysis of limited samples collected during the reconnaissance show that the amount of ^{7}Be in soils is relatively uniform. Radionuclides are found in measurable quantities in the suspended sediment of the Soda Butte/Lamar/Yellowstone system. The amount of ^{7}Be in suspended sediments decreases downstream along Soda Butte Creek from values typical of the soil surface to very low values near the confluence with the Lamar River.

HERPETOLOGY

Project title: **The Distribution and Status of Amphibians and Reptiles in the Greater Yellowstone Ecosystem**

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Additional investigators: Debra Patla, Jeremy Hawk, Char Corkran

Objective: 1) Expand information on the distribution and status of amphibians and reptiles in Yellowstone National Park. 2) Monitor selected amphibian breeding sites to determine changes in species presence and reproductive success. 3) Contribute to adaptive management by conducting surveys, compiling information, and formulating recommendations for the conservation of amphibian and reptile populations in areas that may be affected by development projects or other human activities. 4) Research effectiveness of remote sensing techniques for identifying amphibian breeding sites.

Findings: 1) Distribution: We continued to compile distribution information for amphibians and reptiles. Surveys were conducted in selected areas (see #3 below) and in Fan, Specimen, Bacon Rind, Cache, and upper Lewis River drainages. Observations were entered into a GYE amphibian database. 2) Monitoring: We continued monitoring at seven amphibian breeding sites in YNP (ninth year). 3) Adaptive management: We conducted searches for amphibians in potential habitat along road sections targeted for reconstruction or improvement: Madison to Norris, Canyon to Fishing Bridge, and Canyon to Tower. We surveyed areas potentially targeted for native fish restoration: Fan, Specimen, and Bacon Rind Creeks. Reports documenting species presence and habitat use and providing recommendations for conservation or mitigation were submitted to the park. We also provided documentation and recommendations concerning the effects of management activities (fuel hazard removal and road culvert placement) on two important amphibian breeding sites (Lodge Creek and Tangled Creek). 4) Research: In coordination with a Yellowstone Ecosystem Studies remote sensing project, we conducted surveys to determine amphibian presence in Cache Creek and evaluated the ability of hyper-spectral imagery to detect boreal toad sites.

HYDROLOGY

Project title:	**Rocky Mountain Regional Snowpack Chemistry Monitoring**
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Objective: The extent of atmospheric deposition of engine emissions throughout the park was poorly understood until a pilot study in 1996 by the USGS and National Park Service indicated a correlation between snowmobile use and concentrations of ammonium and sulfate at three locations in the park, including the town of West Yellowstone. Knowledge of the extent of the deposition to annual snowpacks of acids and other compounds associated with fossil-fuel combustion is important to park preservation; it also is important to establish chemical baselines that can be used in evaluations that affect policy decisions controlling vehicle traffic in protected areas. Thus, snowpacks that represent a spectrum of snowmobile use at locations throughout Yellowstone were sampled during March 1999 to measure wintertime deposition of selected inorganic byproducts of gasoline combustion.

Findings: Snowpack samples representing most of the winter precipitation were collected at about the time of maximum annual snow accumulation at a variety of locations in the park to observe the effects of a range of snowmobile traffic levels. Concentrations of inorganic compounds in snow samples during 1999 from pairs of sites located directly in and off snow-packed roadways used by snowmobiles were compared to concentrations in samples collected at nearby off-road sites. Concentrations of ammonium were 2 to 5 times higher for the in-road snow compared to off-road snow for each pair of sites. Thus, concentrations decreased rapidly with distance from roadways. In addition, results from snowpack-chemical analyses for 1998 snowpacks showed concentrations of ammonium, nitrate, sulfate, benzene, and toluene in snow were positively correlated with snowmobile use.

LIMNOLOGY

Project title: **Ecosystem-Level Impacts of the New Zealand Mudsnail to the Firehole River: A Preliminary Study**

Principal investigator: Dr. Robert Hall
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Objective: The objectives of this research are to: 1) develop methods to estimate growth rates and secondary production of *Potamopyrgus*; and 2) to collect necessary preliminary data so that a larger study of the impact of the mudsnail on nutrient transfer through stream food webs may be undertaken. Pretreatment data to be collected are biomass of snail and native invertebrates at one time so that I can estimate potential effect of snail in material cycling within the food web.

Findings: I found that I could paint and recapture snails to estimate growth rate, but this only worked for large sanils that are not growing quickly. Concomitant studies by Dr. Mark Dybdahl show that enclosing snails in small (10 cm) chambers for several weeks is sufficient to measure growth rates. I am still counting and sorting snails and invertebrates to estimate biomass in the Firehole River. Samples for museum collection accession #1815 are being identified and stored in my laboratory until completion of the project.

Project title: **The Biogeochemistry of Sublacustrine Geothermal Vents in Yellowstone Lake**

Principal investigator: Dr. Val Klump
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Additional investigators: Russell Cuhel, James Maki, Tony Remsen, Carmen Aguilar

Objective: Yellowstone Lake is an ecosystem in which closely linked components of microbiology,

geochemistry, and mineral reactivity justify the term "Biogeochemical Cycling". The overall objective is to develop quantitative understanding leading to a biogeochemical flux and mass balance model for hydrothermal vent systems. More specific objectives are as follows: 1) To determine the importance of vent and fumarole emanations relative to shallow groundwater and sediment-water flux in enrichment of major ions of Yellowstone Lake water. 2) To identify short (hours-days) and long-term (annual) variability in submarine vent activity. 3) To assess the potential geochemical interactions with iron during formation of iron oxides formed via vent fluid interactions with cold lake water. 4) To determine the relative importance of abiotic sulfur oxidation and microbially-mediated sulfur oxidation. 5) To determine the specific contributions of photosynthetic, heterotrophic and chemolithotrophic biomass production. 6) To analyze transformations of sulfur by measuring the stable isotope composition of mineral, organic matter, and micro- and macro- organisms. 7) To utilize trace metal concentrations in aqueous and solid phases to evaluate hydrothermal activity and geochemical processes participating in elemental cycling. 8) To estimate the quantitative impact of sublacustrine hydrothermal vents and springs on the biogeochemical mass balance for the lake.

These efforts are intended to lead to a significant quantitative improvement in understanding of biogeochemical dynamics for select parameters. Control of nutrient and trace element cycling involves physical transport (e.g., riverine inflow and outflow, sediment-water flux, hydrothermal venting, groundwater inflow and outflow, mixing), chemical transformation (e.g., sorption by minerals precipitated from vent fluids, precipitation and dissolution, oxidation-reduction transformations), and biological interactions (e.g., assimilation into biomass, energy-yielding oxidation-reduction transformations, organic matter diagnosis). This work will provide background necessary to begin modeling basin-wide fluxes of biogeochemical important elements to elucidate the contribution of geothermally altered groundwater to Yellowstone Lake.

Findings: In the summer of 1999, approximately 14 days of ROV exploration and field operations were successfully completed. New vents and vent fields were discovered in West Thumb at sites previously described by Kaplinski as potential hydrothermal spring areas, based upon his observations and bathymetric charting. The relict hydrothermal features discovered several years ago in Bridge Bay, the so-called "spires", were revisited. These vertical columns, up to 20 feet or more in height, appear to be old hydrothermal "chimneys" reminiscent of similar hydrothermal deposits seen on the mid ocean ridge spreading centers. With the help of the NPS dive team, the Lake Ranger Station, and the NPS research office, a piece of one of these spires (ca. 60 cm x 25 cm, 14 kg), which had apparently broken off at some earlier time, was recovered and brought to the surface. We are currently analyzing this fragment at the Great Lakes WATER Institute of the University of Wisconsin-Milwaukee to determine its potential origin and age. Studies on the interaction between vent hydrochemistry and microbial activity continued. Strong evidence for mineral-dependent bacterial productivity was obtained, a unique feature of Yellowstone Lake. Chemosynthetic production rates are similar to photosynthetic rates on a per liter basis. Studies of near vent plume-mixing and chemical reactions rates also continued with promising results suggesting the utility of Radon-222 as a tracer and reaction rate monitor. Recording thermistors were deployed at a number of sites to obtain a long term (~1 year) record of thermal activity. Additional work on dating of sediments and pore water chemistry was also undertaken. Some of these results will appear in the proceedings of the "Symposium on the Greater Yellowstone GEO-Eco-

system."

Prior to our 1999 field work, we cooperated with the USGS supported- and conducted- multi-beam high precision bathymetric survey of the northern fifth of the lake. The complex topography observed correlated well with our previous in situ studies, and revealed some potentially spectacular and heretofore unseen features on the lake bottom as well. We hope to pursue ground-truthing of these features in the future (2000-01).

MAMMALOGY

Project title:	**Fecundity and Fawn Mortality of Northern Yellowstone Pronghorn**
Principal investigator:	Dr. John Byers
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Address:	Department of Biological Sciences University of Idaho Moscow, ID 83844-3051
Additional investigators:	Mary Robinson

Objective: The purpose of this research is to measure annual pregnancy rate, litter size, and litter mass of pronghorn females in Yellowstone National Park and to measure the death rate and ages at death of pronghorn fawns. This information is required to monitor the health and trend of this small, isolated pronghorn population and to estimate its likelihood of persistence over the long-term. This information is also critical for development of an intervention plan, should one become necessary, to save this indigenous population.

Findings: In February 1999 we contracted for the capture of 30 pronghorn females. Females were individually restrained using a net gun fired from a helicopter. Each female was fitted with a radio collar. In May-June 1999 we located females daily, or as frequently as possible, to record birth date and litter size. We captured fawns of these females and recorded mass. We attached solar-powered ear tag transmitters to some fawns. In June-August 1999 we located females daily, or as frequently as possible, to record estrus date.

Results from this first field season should be considered as preliminary. Seven radio-collared females died between February and May 1999. Of those, two were within 14 days post-capture and therefore may have been capture-related. Coyotes appear to have also played a role in at least one of the mortalities, but it is not known whether stress or minor injury (e.g., bruising) from recent capture predisposed that animal to predation. Five collared pronghorn died within the next three months, but all were more than 14 days post-capture and are therefore not considered capture-related. Of those five, two were known coyote predation, one was probable coyote predation, one was from lion predation, and one was from unknown causes (not enough remains were present to determine cause). Twenty of the 23 (87%) collared does were pregnant at the commencement of monitoring on May 17. Three does were neither pregnant nor lactating at the commencement of monitoring; it is unknown if they gave birth and lost their fawns soon thereafter or were not pregnant this summer.

The births of one single fawn (doe 193) and two sets of twins (does 224 and 374) were observed. This small sample is not sufficient to estimate litter size. We observed or inferred the existence of 23 fawns that were born to collared females. Five of these fawns were never seen, but their existence was inferred by lactation of the mother. Ten fawns (5 males and 5 females) of the 23 were captured, at 1-4 days of age. All captured were in good condition. Six fawns (26%) survived to the end of monitoring on October 7. Of the 17 that died, five were at uncertain age, but within the first three weeks of life. Of the remaining 12 deaths, five were within postnatal days 1-7, two within days 8-14, and three within days 15-21. Estrus dates were recorded between September 20 and October 2, with a peak at September 23 - 30.

Project title:	**Small Mammal Communties: Prey-Base for Carnivores**
Principal investigator:	Dr. Robert Crabtree
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Additional investigators:	D. Despain, K. Wilson, K. Johnson

Objective: 1) Develop an inventory and monitoring method for small mammals (carnivore prey base) on Yellowstone's northern range. 2) Describe and quantify the effects of the 1988 fires on the small mammal community. 3) Quantify habitat use of the major small mammal prey. 4) Estimate abundance of major small mammal prey on the northern range according to major habitat types. 5) Collaborate with cooperating parties. 6) Continue long-term monitoring of small mammal populations, especially the major prey species.

Findings: Final report and book chapter have been completed. Various scientific publications are now being prepared. Significant effects of the 1988 fires have been documented. Dr. Kenneth Wilson of Colorado State University is currently working with PI to write three manuscripts for submission to scientific journals. Fieldwork was conducted in July and August to monitor small mammal populations in the Lamar Valley area.

Project title: **Physiological Stress Responses, Aggression and Social Dominance in Free Ranging Wolves**

Principal investigator: Dr. Scott Creel
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Additional investigators: Jennifer Sands

Objective: 1) Determine factors that affect stress hormone levels in free-ranging wolves. This includes behavioral, ecological, and anthropogenic influences. 2) Relate stress physiology to survival and reproduction. 3) Relate stress physiology to social status.

Findings: We conducted our first full season of field research in the winter of 1998-1999. We have collected approximately 200 fecal samples since January 1999 from both known individuals, and where this was not possible, known pack. We have collected 100+ hours of observations of wolves that we are beginning to analyze for rates of aggressive interactions and dominance relationships. Our research has focused on the Druid, Rose Creek and Leopold packs in the northern range of the park. We have finished running the glucocorticoid radioimmunoassays of the fecal samples collected last field season and are beginning to analyze this data. We will also run radioimmunoassays for sex steroids (estrogen, estradiol, and testosterone) beginning this spring. Our second field season began January 15, 2000, and we intend to continue fieldwork through May and return next fall during the intensive wolf winter study in November 2000.

Project title: **Grizzly Bear Behavior, Genetics and Ecology**

Principal investigator: Dr. Steven French
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Additional investigators: Marilyn G. French

Objective: The threatened Yellowstone grizzly bear represents a bellwether population for many other endangered species of predators. The successful long-term conservation of this population requires two crucial pieces of data: managers need to know the number of grizzly bears in the ecosystem, and they need an accurate assessment of the population trend over time. They also need to ensure that the population does not suffer from a loss of genetic diversity. Our project is designed to apply the tech-

niques of molecular genetics to aid the conservation of grizzly bears in the Yellowstone ecosystem. The primary aims of the project are to assess the degree of genetic diversity in the Yellowstone population, and to use molecular techniques to develop a non-invasive system to accurately monitor the number of grizzly bears in the ecosystem.

Findings: We have completed the development of 35 nuclear DNA micro-satellites for Yellowstone Grizzly Bears. A total of 195 grizzly bear DNA samples have been genotyped using these loci. We have also compared the genetic diversity among bears from Banff, NCDE, Yellowstone, and Kodiak using these loci. Two manuscripts are in preparation for scientific publication. Once accepted, the results, including technical data for the loci and the primus, will be released to the general public via the Internet. Hard copies of the manuscripts will be sent to interested parties.

Project title: **Development of Aerial Survey Methodology for Bison Population Estimation in Yellowstone National Park**

Principal investigator: Dr. Robert Garrott
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Additional investigators: Steven C. Hess, L. Lee Eberhardt

Objective: The overall objective of this study is the development of aerial survey methodologies for statistically rigorous estimation of the bison population in the Yellowstone area that will have sufficient power and precision to detect demographic trends. These methodologies will allow NPS resource managers to conduct aerial surveys that provide scientifically defensible population estimates to address ecological conditions and epidemiological management issues of Yellowstone bison.

Findings: The survey methodology we are developing quantifies a sampling universe and sampling units with computer geographic information system, standardizes search effort, employs a stratified sampling design which accounts for undetected animals, and uses an aircraft global positioning system to record data locations. Including seasonally occupied areas outside YNP boundaries, 76 survey units with area of 2,339 km^2 comprise the entirety of our designated survey extent, roughly equivalent to 26% of the area of YNP. The same survey units and total extent are used both in winter and in summer, but survey units have different strata designations for each season. During winter, 52% of the entire survey area is designated to be in the high density stratum, while in summer, 41% of this area is in the high density stratum. For this research, we enumerated all survey units in the seasonal high density stratum. During our 1998 winter and summer field seasons, we completed 17 flights totaling 56.4 hours of bison surveys, not including ferry time. During our 1999 field seasons, we completed 16 flights totaling 49.6 hours.

Concurrent intensive ground surveys, or "double sampling," in the Madison-Gibbon-Firehole areas in winter were used to estimate the magnitude and variability in detectability during specific aerial surveys. In comparing these simultaneous ground and aerial surveys primarily in winter, only 84.3% of the groups were detected from aircraft, although 94.8% of individual bison were detected. During the summer breeding period, as much as 70% of the entire bison population is aggregated in significantly larger, highly visible groups in Hayden Valley than observed during winter. Conducting surveys during this time may provide for both higher detectability of groups and smaller spatial extent than in winter, when bison occupy a larger area and occupy thermal habitats which have unfavorable background color. We found detectability to be relatively high in comparison to aerial surveys of other species, although many small groups and solitary bison were not detected from aircraft, which biases population estimates downward. Low variability between counts and high detectability suggest that precise and unbiased population estimates should be readily obtainable.

Project title:	**Some Population Characteristics of the Yellowstone National Park Bison Herd, 1996-20001**
Principal investigator:	Dr. Peter Gogan
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Address:	USGS-BRD Department of Biology Montana State University Bozeman, MT 59717
Additional investigators:	Wendy E. Clark, Edward M. Olexa, John A. Mack

Objective: To determine basic population parameters of Yellowstone National Park bison herd.

Findings: Samples were secured opportunistically from bison slaughtered beyond the boundaries of YNP during the winter of 1996-97. We found marked differences in the age structure of bison killed in the vicinity of West Yellowstone and Gardiner. This difference is likely attributable to largely non-selective removals at West Yellowstone and selective removals at Gardiner. Pregnancy rates increased continuously between one and six years of age. Cross-referencing of our age data with Montana Department of Livestock seroprevalence data revealed a general upward trend in seroprevalence with age for female bison. Our sample of male bison was too limited for this comparison.

We secured samples from 69 of the 87 (79%) slaughtered in the vicinity of West Yellowstone in the winter 1998-1999. Data on these bison were gathered in cooperation with the Montana Department of Livestock and USDA's APHIS. Sampled bison ranged in age from 1 to 11 years old. With the exception of a single eight-year-old, all sampled females were pregnant.

Project title: **Ecological Status of Mule Deer of the Northern Yellowstone Winter Range**

Principal investigator: Dr. Peter Gogan
Phone number: See previous entry

Additional investigators: Edward Olexa, Tom Lemke

Objective: 1) Determine the summer ranges of deer utilizing the northern winter range. 2) Determine use patterns of deer on the northern winter range. 3) Determine annual reproductive performance and fawn survival. 4) Determine numbers, age, and sex structure of the wintering herd.

Findings: This study has been conducted under the auspices of the Northern Yellowstone Cooperative Wildlife Working Group. Sixty adult doe mule deer were net-gunned and radio-collared on the northern range in March 1993. An additional 25 adult does were captured and radio-collared in March 1995. Animals were located from a fixed-wing aircraft at approximately 10-day intervals between April 1993 and May 1997. Locations were determined with a GPS unit in the aircraft. Age and sex composition counts were completed in early winter and total counts and adult:fawn ratios were completed in May of each year.

Radio-tracking data reveal that mule deer wintering in the Gardiner Basin on the east side of the Yellowstone River summer to the east of the winter range with one exception. Some deer wintering in the Slip 'n Slide drainage moved to the west to the vicinity of Big Sky, Montana. Similarly, deer wintering on the west side of the Yellowstone River summer to the southwest of the winter range. Data on the age and sex composition for the period of study have been combined with previously published information to track population trends. Analysis reveals that fawn survival is closely linked to an index of winter severity, particularly to snow water equivalency.

Project title: **Seasonal Movements and Habitat Selection by Bison in YNP**

Principal investigator: Dr. Peter Gogan
Phone number: See previous entry

Additional investigators: Edward M. Olexa, John Mack

Objective: To determine movement patterns of YNP bison and relate these movements to range conditions such as herbaceous standing crop, growth stage, snow depth, and snow water equivalency in the areas vacated and occupied by bison.

Findings: Forty-five bison were net-gunned and radio-collared in October 1997. An additional 40 bison were radio-collared as part of on-going epidemiological studies of bison and brucellosis. Five bull bison were net-gunned and radio-collared on the northern range in March 1998. Aerial radio-tracking flights

for all instrumented bison have been on-going since that time. Bison are being relocated at approximately 10-day intervals. Locations are being determined with a differentially correcting GPS unit in the aircraft.

Thirty of the original 45 instrumented bison were recaptured and fitted with improved radio collars in October 1998. Eighty-three bison were being radio-tracked at that time. We were radio-tracking 64 bison by October 1999. Since the inception of the study, there have been 25 known mortalities, 12 bison that lost their collars, and four bison that either shed their collars or died.

Project title:	**Monitoring the Response of Small Mammal Communities to Climatic Change Using Raptor Pellets**
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Additional investigators:	April Craighead

Objective: The objective of this project was to establish roosting and nesting sites of common raptors in different habitats within Yellowstone National Park. Pellets were collected and analyzed to determine prey species in the diets of these raptors. The species within the pellets will then be analyzed to determine whether specific habitats can be determined using certain raptor pellets.

Findings: During the field seasons of 1998-99, 1,240 raptor pellets were collected from six different species of raptors, and 52 coyote scats were collected from four distinct habitats within Yellowstone National Park. These habitats included xeric grass/shrublands to mesic grasslands.

Analysis of 700 pellets and 52 scats indicate the diet of these animals is quite diverse, and includes rodents, birds, amphibians, snakes, and insects. The most commom species in the pellets and scats include voles (*Microtus spp.*), northern pocket gophers (*Thomomys talpoides*), deer mice (*Peromyscus maniculatus*) and Uinta ground squirrels (*Spermophilus armatus*). Repository of this collection will be at Stanford University in California.

Project title: **Bat Survey Along the Madison-Norris Road Corridor**

Principal investigator: Dr. Paul Hendricks
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Additional investigators: Roy Renkin

Objective: The objective was to document bat activity along the road corridor between Norris Junction and Madison Junction in Yellowstone National Park. Sites to be inspected and monitored included: 1) bridges; 2) selected thermal areas; and 3) wetland, forest, and cliff sites. Mist-net trapping and overnight monitoring with electronic bat detectors were part of the sampling scheme.

Findings: Results have not been analyzed, so these findings are preliminary. Six bridges along or over the Gibbon River were inspected for evidence of use by bats. Three bridges contained guano accumulations. The bridge at Madison Junction is not suitable for use by bats; the remaining five structures could be used. Sites under bridges used included exposed stell beams adjacent to concrete or stone pilings. Few sites were mist-netted, and only one bat (a male little brown *Myotis*) was captured. Twenty-one sites were monitored overnight with bat detectors. Of these, bat activity was detected at 17 sites. Bats were also monitored one evening at Norris Campground. At least two species were actively foraging at treetop (30-40 ft above ground), beginning at 19:40 and continuing until monitoring ceased (21:15). Activity diminished quickly as temperature dropped. More bats undoubtedly use the road corridor than these results indicate. Fieldwork was conducted from September 20-25, when many bats had probably already left the park.

Project title: **The Dietary and Foraging Ecology of the Yellowstone River Otter: An Umbrella Species for Aquatic Systems**

Principal investigator: Dr. Douglas Kelt
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Additional investigators: Bill Wengeler, Nathan Varley

Objective: We propose to clarify the ecological role of native vs. non-native fish species on

Yellowstone river otters by comparing otter populations on two lake systems in YNP: Yellowstone Lake, where the native cutthroat population is still healthy, and the Lewis-Shoshone Lake complex, in which non-native fish, primarily lake trout and brown trout, predominate. Specifically, we intend to characterize river otter diets through fecal analysis and document otter foraging habits by observing daily activity patterns. Furthermore, we are currently considering the use of stable isotope analysis to determine the trophic levels at which otters and their prey exist. The data generated by this research will help assess the consequences of the lake trout invasion on a predator whose existence is firmly linked to aquatic systems and may prove critical to the future management of Yellowstone waters.

Findings: This project began in the summer of 1999 with surveys for otter sign, scat collection, and the acquisition of fish samples (lake, brown, and cutthroat trout of various age/size classes) from park biologists. The fish samples have been prepared for purposes of establishing reference collections with which to compare otter fecal contents. Approximately 100 river otter fecal samples were collected between August and November. We are currently analyzing fecal samples in the lab and characterizing otter diet by the frequency of occurrence of various prey items. Numbers of prey items, prey species, and size are estimated on the basis of otoliths, vertebrae, and other appropriate skeletal structures. Pending permit approval, collection of samples will resume in January 2000. Specimens will be housed at the U.C. Davis anthropolgy museum.

Project title: **Impact of Wolf Reintroductions on the Foraging Efficiency of Elk and Bison**

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Additional investigators: Lucina Hernandez

Objective: Determine what impacts the reintroduction of wolves might have on the foraging efficiency and thus, the survival of elk and bison in Yellowstone National Park.

Findings: During 1999, 250 feeding bouts by elk and bison were observed. Of these, approximately half were in the area where wolves currently occur and the other half in areas where wolves have yet to establish. In both areas, the observation bouts were equally divided among males, females with calves, and females without calves. Results of analysis of the date for 1996 indicated that female elk with calves and females without calves foraged significantly less and surveyed significantly more in the area where wolves were. There was no difference for males. Data from 1997 indicated the same significant differences for females. Additionally, both female groups foraged significantly less and surveyed signifi-

cantly more in areas with wolves in 1997 over their 1996 rates. Additionally, females with calves spend even less time feeding and more time observing than females without calves. Analysis of data from 1998 indicate a similar pattern as found for 1997. This suggests that elk in wolf areas stabilized their level of vigilance.

In 1998, data were also collected on the vigilance of bison in wolf and non wolf areas. Results of those data indicate that bison too, are responding to the presence of wolves with a similar pattern: no response by males, an intermediate response by females without calves and the greatest response by females with calves. Data were also collected on the distribution of pellet groups (elk) and fecal piles (bison) relative to the distance from forest edges. Preliminary analyses for areas with wolves indicate that significantly fewer elk pellet groups were found in open areas greater that 300 meters from forest edges. This pattern was not found in non-wolf areas. A similar trend was seen in the 1999 data. Thus, elk seem to be responding to the presence of wolves by shifting their habitat use while we have not seen this effect in bison. Analysis of fecal nitrogen, phosphorous, and protein in elk indicates significantly lower levels of these components in the diets of elk from areas with wolves. No difference was seen in the diets of bison. Thus, elk seem to be consuming a poorer diet in wolf areas vs. non wolf areas.

Research efforts this year will be to determine if the patterns of vigilance are consistent over another year. This year's data collection could allow before and after comparisons in areas where wolves weren't before but have subsequently become established. We will also collect more data on the distribution of elk and bison relative to forest edge and diet quality in wolf and non-wolf areas.

Project title: **Winter Bison Monitoring**

Principal investigator: Yellowstone Bison Management Office
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Yellowstone National Park, WY 82190

Additional investigators: Yellowstone National Park personnel

Objective: The objective of this monitoring effort is to determine bison location, movement and use of the Fishing Bridge to Canyon and Mammoth to Gibbon Falls road segments, as well as the surrounding area along the road corridors during the winter of 1998-99.

Findings: Each of the road segments was monitored from December 8 through mid-March with a combination of ground surveys, photo-points, and aerial surveys. A total of 64 ground surveys were completed in each study area. A total of 2,458 bison group observations were recorded during this period. Of the 2,458 observations, 5.8% (58) in Mammoth and 9.4% (137) in Hayden Valley were documented on the roads, as compared to 2% (26) in Hayden in 1997-98. Aerial survey results indi-

cated that the number of bison remained fairly stable in both study areas between December and February. Bison numbers changed substantially, however, during the month of March, more than doubling in the Mammoth study area and decreasing by nearly 25% in the Hayden study area. A total of 2,299 pictures were taken, 8% (184) recording bison. Of the 184 sightings, 8% (14) were of bison on the groomed road surface.

Project title:	**The Effect of Environmental Variability on Grizzly Bear Habitat Use**
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Address:	USGS Northern Rocky Mountain Science Center Interagency Grizzly Bear Study Team Forestry Science Lab Montana State University Bozeman, MT 59716
Additional investigators:	Robert Garrott, Charles Schwartz, Steve Cherry, Richard Aspinall

Objective: The overall design of this project is to utilize existing data, expertise, and newly collected data from advanced technologies to evaluate the impact of anthropomorphic influences on grizzly bear (*Ursus arctos horribilis*) habitat selection. Initially, this study will have three areas of emphasis: 1) impact of motorized and non-motorized trails on grizzly bear habitat selection; 2) habitat selection by grizzly bears within Yellowstone National Park versus those outside of the Yellowstone National Park; 3) similarities and dissimilarities in delineating grizzly bear home ranges when collecting locational information with different technologies.

Findings: The first year objective of this project was to deploy Global Positioning System (GPS) collars on grizzly bears in northern and northwestern portions of the Yellowstone National Park and surrounding Forest Service land making up the study area. The collars selected for this project were Advanced Telemetry System collars instrumented with GPS receivers and very high frequency (VHF) transmitters.

The main advantages to collars with the GPS technology are safety to researchers, minimized handling of each bear, and the amount of information gained on habitat use. After the GPS collar has been placed on the bear, locational information is automatically gathered on a predetermined schedule, without any intervention of the researcher. For the initial data collection period, the collars were programmed to collect locations every seven hours. Thus, there was a potential of collecting a minimum of three locations each day as compared to VHF technologies where researchers have gotten a location approximately once every ten days. The collars were also instrumented with remote release devices designed to release without handling the bear a second time. Once the collar had been dropped, VHF receivers were used to locate and retrieve the collars.

For this study the IGBST was able to instrument 12 bears during the 1999 season. Of the 12 grizzly bears collared, five were adult females and seven were adult males. The first collar was deployed on May 6, 1999, and the last collar was deployed on August 12, 1999. These collars collected data throughout the non-denning season before they were remotely released. Collars ranged in success of location acquisition rate from a high of 48% to a low of 7.2%. In the following years the researchers hope this rate will increase to above 65% by changing collar design. Next year the researchers plan to use a collar that will stay on for 12 months and record locations during the non-denning months (April 15 through November 15) at a rate of four locations per day. This collar will automatically drop off at the end of the 12 month period. In addition to the collection information on grizzly bears, the researchers will be updating the current grizzly bear habitat with current satellite imagery.

Project title: **Population Dynamics of the Yellowstone Grizzly Bear**

Principal investigator: Dr. Charles Schwartz
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Bozeman, MT 59716

Additional investigators: Mark Haroldson

Objective: To describe the population trend from threatened status to recovery and approximate stability.

Findings: These data include information collected by the Interagency Grizzly Bear Study Team for the entire Greater Yellowstone Area. Data obtained within YNP is not broken out separately. Forty-two individual grizzly bears were captured 47 times during the 1999 field season. Sixteen captures of 15 bears were the result of management actions. Thirteen of these instances resulted in relocation of the nuisance bear(s). A total of 1,109 aerial radio locations were obtained on 65 individual grizzly bears radio-monitored during all or some portion of 1999. Nineteen of these bears were adult females. Two rounds of observation flights were conducted as part of a capture-mark-resight experiment. Flights covered the entire grizzly bear recovery zone plus a 10-mile perimeter. The first round of flights began June 7. Forty bears, none of which were radio-marked, were observed during 79.6 hours of flying. Twenty-nine radio-marked bears were available for observation within survey units. The second round of flights began on July 8, and 45 bears, including one marked individual, were observed during 74.5 hours of flying. Thirty-one marked bears were located within survey units. Thirty-three unduplicated females with cubs of the year were identified during 1999. Three of these unique females were initially observed outside the grizzly bear recovery zone; one of the three was initially observed outside the 10-

mile perimeter. A total of 63 cubs were observed during the initial sightings of these females. Eleven single cub litters, 17 litters of twins, and 9 litters of triplets were observed. Mean litter size was 1.9. Females with young (cubs, yearlings, or 2-year-olds) were observed in 17 of 18 Bear Management Units within the grizzly bear recovery zone. We documented six known and one probable human-caused grizzly bear mortalities during 1999. One management removal occurred more than 10 miles from the boundary of the grizzly bear recovery zone. Two known and four probable mortalities of cubs were also documented. One radio collared bear was found dead from unknown causes. Yellowstone Grizzly Bear Investigations for 1995-1998 are now available at: *www.mesc.usgs.gov/yellowstone/IGBST-home.htm*. The 1999 annual report will be available by May 2000.

Project title:	**Food Habits and Habitat Use of the Yellowstone Grizzly Bear**
Principal investigator:	Dr. Charles Schwartz
Phone number:	See previous entry
Additional investigators:	Mark Haroldson, Shannon Podruzny, Doug Ouren

Objective: To determine habitat requirements for the Yellowstone grizzly bear and to document its return to free-ranging status.

Findings: Surveys to determine an index of spring ungulate carcass availability were conducted during May. Approximately 300 km of transect routes were surveyed in four different ungulate wintering areas. We observed 0.25 ungulate carcasses/km. A relatively small number of winter killed ungulates were available to bears during the spring of 1999. Surveys of numbers of spawning cutthroat trout and their use by grizzly bears were conducted from mid-May to early August on tributary streams to Yellowstone Lake. Spawner numbers were high in most streams surveyed except those in the West Thumb area. Three hundred and eighty-six hair samples suitable for DNA analysis were collected near spawning streams. These samples will be used to estimate of the number of individual grizzly bears that fish for spawning cutthroat trout. Surveys of 19 whitebark pine cone productivity transects were completed during July. The number of mean cones per tree was 39.5. This was the second highest average since the whitebark pine cone production transects were initiated in 1980. A total of 152 grizzly bear observations were recorded at 26 known and/or suspected insect aggregation sites during late July through September of 1999. One hundred and fifty-one scats were collected and will be analyzed to identify food items used. Yellowstone grizzly bear investigations for 1995-1998 are now available at: *www.mesc.usgs.gov/yellowstone/IGBST-home.htm*. The 1999 annual report will be available by May 2000.

MANAGEMENT

Project title: **Scientific Research in Yellowstone National Park: An Internet Searchable Bibliographic Database**

Principal investigator: Cynthia Stewart Kaag
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Address: Washington State University
Head of Science Libraries
Owen S&E Library
Pullman, WA 99164-3200

Objective: Maintain and expand a fully searchable Internet database of published and unpublished findings from scientific research carried out in Yellowstone National Park.

Findings: Database available at: *www.wsulibs.wsu.edu/yellowstone/*. Ongoing project; currently ca. 9,800 unique entries. The web site is linked from the Yellowstone National Park homepage. I am working with the Yellowstone Center for Resources and the National Park Service Natural Resources Bibliography project to provide as complete coverage as possible. Most entries have abstracts; all have assigned subject headings.

MICROBIOLOGY

Project title: **Bacteria Living at Low pH and High Temperature**

Principal investigator: Dr. Rick Bizzoco
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Address: Department of Biology
San Diego State University
5500 Campanile Drive
San Diego, CA 92182-4614

Objective: Discovery of new hyperthermal acidophiles.

Findings: We have identified several new organisms in our electron microscopic analysis. Phase-contrast microscopy has revealed numerous morphological types in the hot springs we have examined. DNA staining was performed to document that the forms observed indeed were biological entities and/or living microbial cells. We compared these findings with those obtained in 1971 while working with Professor T. Brock.

Project title: **Transition between Lithoautotrophy and Chemoheterotrophy in *Sulfolobus* species**

Principal investigator: Dr. Paul Blum
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School of Biological Sciences
University Nebraska-Lincoln
Lincoln, NE 68588-0666

Objective: To determine the factors which regulate the metabolic status of cells in situ.

Findings: None within the year 1999.

Project title: **Molecular Ecology of Photosynthetic Hot Spring Bacteria that Resemble *Heliothrix oregonenesis***

Principal investigator: Dr. Sarah Boomer
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Email: *boomers@wou.edu*
Address: Department of Biology
Western Oregon University
345 Monmouth Avenue
Monmouth, OR 97361

Objective: The goal of this research is to survey thermal areas of Yellowstone for new representatives of hot spring bacteria that resemble *Heliothrix oregonensis*, a photosynthetic bacteria that has been described in alkaline hot springs in the Oregon Cascades. Evidence from other labs and ours suggests that *Heliothrix*-like organisms are prevalent in similar habitats in Yellowstone National Park. Using DNA/molecular methods, we isolate bacterial DNA from new mat samples containing *Heliothrix*-like bacteria, as suggested by habitat, microscopic, and photosynthetic pigment analysis. From this DNA, we amplify and sequence 16S rRNA genes, genes used for identification purposes. Sequences obtained are compared to national DNA databases and used to identify and classify novel strains, thus determining the precise relationships between a) the new organisms and *Heliothrix*; or b) different isolates within Yellowstone National Park.

Findings: Over the summer of 1999, five undergraduates and I surveyed four distinct areas, performing habitat analysis in the field. Of these, we ruled out three areas based on habitat parameters (Canyon/Seven Mile Hole and Factory Hill/Columbia group, both near Heart Lake) and removed samples from one mat in the Witch Creek drainage near Heart Lake. Further microscopic and pigment analysis of this site following the field trip confirmed the presence of *Heliothrix*-like bacteria. We also surveyed and sampled three previously sampled sites (Spray/Fairy and Hillside) in order to document mat growth/recovery following the 1998 trip and collected material so as to determine the amount of genetic variability that occurs over time in these important sites. Presently, two undergraduates are characterizing 16S rRNA clones from the Hillside-1999 samples. To date, they have twenty-four different clones and are in the process of sequencing them.

Project title: **Recognizing the Signatures of Hyperthermophilic Biofilms within Hydrothermal Ecosystems and their Fossilized Deposits**

Principal investigator: Dr. Sherry Cady
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Department of Geology
17 Cramer Hall, 1721 SW Broadway
Portland, OR 97207

Additional investigators: Zach Oestreicher, Liz McKenzie

Objective: To understand how hyperthermophilic communities that occupy modern hydrothermal ecosystems are preserved in the rock record in order to enhance our ability to properly interpret their fossilized counterparts. Given that hydrothermal deposits are targets for future Mars missions, we are establishing criteria for the detection and proper interpretation of hyperthermophilic biosignatures found in a variety of different types of siliceous sinters. The strategy relies on characterizing the biogeochemical signatures of modern hyperthermophilic communities using a combination of field, experimental, and analytical techniques (i.e., quantitative mineralogy and petrography, electron beam microscopy and chemical analysis, isotopic and biomarker compound analysis, and, in collaboration with N.R. Pace's group, molecular phylogenetic identification).

Findings: We have identified that although organically preserved hyperthermophilic microfossils are rarely preserved in high temperature siliceous sinter deposits, hyperthermophiles are preserved as microfossils by other processes. Our findings indicate that the characteristics of the organisms and the geochemical conditions of the surrounding environment play a role in determining the fidelity of preservation of morphological biosignatures. We are currently using a variety of optical and submicroscopic hybridization probes to better understand the exact mechanisms responsible for the preservation of the hyperthermophilic biosignatures that we have observed in siliceous sinters. In collaboration with the Pace Lab, we continue to document the biogeographical distribution of hyperthermophilic organisms in hot springs and geysers. We have also discovered that differences in the architecture of hyperthermophilic biofilms can be related to differences in the microstructure of siliceous sinters, and we are investigating the potential for sinter microstructures to serve as important biosignatures.

Project title: **Adaptations of Cyanobacteria to High Solar Irradiance: UV Tolerance Strategies**

Principal investigator: Dr. Richard Castenholz
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Eugene, OR 97403-1210

Additional investigators: Jesse Dillon, Scott Miller

Objective: One objective was to evaluate the role of the UV-absorbing pigment, scytonemin, in increasing the fitness of cyanobacteria exposed to high solar irradiance. A second objective was to determine if the exclusion of UV radiation over a hot spring mat composed of several species of cyanobacteria for a two month period would result in changes in species composition, i.e., allow less UV-resistant species to become dominant.

Findings: One study measured differences in responses to UV in two hot spring populations of the same species of cyanobacteria. In the comparison between these two streams, differences in growth and UV responses were observed. The evidence suggests that an unknown toxic substance is present in one of the streams that is inhibiting growth and promoting the production of the UV-screening pigment, scytonemin, compared to the sister population in the other stream. The presence of scytonemin was correlated with a lower percent inhibition by UV radiation, as compared to the same species with no scytonemin in Rabbit Creek. In another related study, populations of other cyanobacteria in two hot spring streams were subjected for two months under UV-excluding filters. Results indicate that there was no significant change in composition unless total irradiance was decreased.

Project title: **Heat Stable Enzymes from Thermophiles**

Principal investigator: Dr. Joan Combie
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Address: Montana Biotech Corporation
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Belgrade, Montana 59714

Additional investigators: Fred G. Albert

Findings: Eight samples were collected for a student at the University of Warwick working under Dr. Paul Norris. No other work was done in Yellowstone or on heat stable enzymes in 1999.

Project title: **Isolation and Characterization of Microorganisms Extremely Resistant to DNA Damage**

Principal investigator: Dr. Jocelyne DiRuggiero
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Additional investigators: Frank T. Robb

Objective: Very little is known about strategies adopted by extremophiles to maintain the integrity of their genetic material in very hot environments. For all cells to survive, they must continuously and accurately repair lesions to their DNA caused by environmental stress. For hyperthermophiles, additional damages are inflicted on their DNA by exposure to elevated temperature. In preliminary studies, we have found that the hyperthermophile *Pyrococcus furiosus* is extremely resistant to ionizing radiation. Based on these observations, we propose the following hypothesis: "Hyperthermophiles' resistance to ionizing radiation is due to their unusual ability to repair extensive heat induced DNA double-strand breaks, which occur at a much higher rate at elevated temperature. Therefore, hot environments should also be a prime source of highly radioresistant microorganisms."

The proposed project addresses the following questions: What are the highest temperatures under which genome integrity can be maintained? How do hyperthermophiles protect and repair their DNA? To address these questions, we will isolate and characterize novel and highly resistant thermophiles from hot springs in Yellowstone National Park containing elevated radon levels and exposed to high fluxes of solar radiation. In addition, we will use extreme UV- and g-irradiation as selective pressure during enrichment to eliminate competing radiation sensitive microorganisms. We will investigate the accumulation of DNA lesions from exposure to sublethal doses of radiation and the kinetics of removal of those lesions with the most radiation resistant isolates. We will assess the performance of the new isolates under simulated space conditions at NASA Goddard Space Flight Center and at the National Institute of Standard and Technology Synchrotron facility. Long-duration tests will determine the performance limits of the isolates exhibiting the greatest survival potential. In addition, survival and recovery of microbial isolates will be measured after their exposure to full spectrum solar radiation during a Solar Extreme Ultraviolet Rocket Telescope and Spectrograph (SERTS) flight.

Findings: We have completed our sampling expedition to Yellowstone National Park. Samples spanning a wide range of temperature, pH, and UV-radiation exposures have been collected. Physico-chemical parameters such as temperature, pH, and radon levels were compiled for each sampling site. Radon was measured in spring water using a a-scintillometer and the technique previously described by our collaborator Dr. M. Reimer. For each sampling site, GPS measurements and digital pictures were also accumulated. We are currently conducting enrichment cultures for the isolation of microorganisms from our

Yellowstone samples. A wide variety of culture media, solid and liquid, have been inoculated with water and sediments collected in hot springs of the park. Incubation temperature varies from 65 to 98° C in anaerobic and aerobic conditions. We are particularly interested in *Deinococcus/Thermus* types of microorganisms that have the potential to be extremely radiation resistant and to grow at high temperature. Prior to further isolation, we are also submitting enrichment cultures to desiccation, UVC, and g-irradiation. The end products will be compared to control enrichment which have not been treated. Five purified cultures have already been obtained and growth curves and partial 16S rRNA sequences are being established for these microorganisms.

In parallel, we have also started testing control microorganisms for hard vacuum conditions. The following cultures have been exposed to hard vacuum in the SERTS instrument at the GSFC: 1) *Deinococcus radiodurans*, growing optimally at 30° C, the most ionizing radiation resistant organism known; 2) *Pyrococcus furiosus* growing optimally at 100° C and extremely resistant to g-irradiation; and 3) dormant spores of *Actimomycete* strains CHR3 and CHR28. The cells were desiccated and exposed to the SERTS vacuum for 4 days. We are currently evaluating the survival of those cells, compared to control cells that have only been desiccated and maintained at atmospheric pressure.

Project title: **Biosedimentology, Microbiology, and Geochemistry of Modern Hot Springs**

Principal investigator: Dr. Jack D. Farmer
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Department of Geology
P.O. Box 871404
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Additional investigators: David J. Des Marais, Linda Jahnke

Objective: The objective of our research is to carry out integrated microbiological and geochemical studies of stromatolite-forming microbial mat systems in modern and ancient hot springs over a broad range of spring temperatures and compositions. Specifically, we wish to understand the factors that control the fossilization and long-term preservation of microbial biosignatures in hot spring sinters. Toward that end, we have been characterizing modern sinter deposits and their associated microbiotas over a broad range of temperatures, pH conditions, and spatial scales. This work provides a basis for comparing ancient thermal spring sinters from localities within Yellowstone National Park, as well as other hydrothermal areas of the world. The key questions in modern-ancient comparisons center around the long-term retention of microbial biosignatures during early and late diagenesis, and the geological and paleontological record of Precambrian hydrothermal environments and their evolution.

Findings: We have described the major and micro-scale features of terraced travertine deposits and

their biosedimentology based on comparative studies at Mammoth Terrace and Gardiner. We have also conducted detailed geochemical studies (stable isotopes, major and minor element variations) at Angel Terrace in the last year and now have obtained similar data for Hillside Springs. We have completed our initial taphonomic studies of microbial mats in siliceous and travertine springs. This included measuring microprofiles in oxygen, pH, and sulfide for microbial mats at Angel Terrace, Fountain Paint Pots, and Octopus Springs. Next year or so we intend to complete geochemical studies of ancient travertines (Highland Terrace and Gardiner), explore for ancient siliceous spring deposits in the Artist Point area, complete mineralogical studies at Hillside Springs, and begin collaborative work on mat biogeochemistry.

Project title: **Protein Comparison of Thermophiles and Oral Bacteria**

Principal investigator: Dr. Richard Gregory
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Indianapolis, IN 46202

Objective: Oral bacterial microflora are extremely diverse (more than 300 different species in the normal oral cavity) and have to survive relatively large temperature and nutritional variations. Thermophilic microorganisms have been fairly well described, but no comparison has been reported with oral bacteria. It is proposed here to compare protein antigens between thermophilic and oral bacteria by immunological and electrophoretic (protein size) techniques. SDS-PAGE electrophoresis will be used to compare the sizes of proteins between representative thermophiles and laboratory strains of oral streptococci (primarily *Streptococcus mutans*, the causative agent of human dental caries). Immunological assays such as ELISA and western blots will be used to compare reactivity between antibodies to protein antigens on *S. mutans* and the thermophiles. It is anticipated that similar proteins will be observed between thermophiles and oral bacteria implying a possible common ancestry.

Findings: Bacterial colonies were isolated on both selective and non-selective petri plates. Selected colonies were propagated and stored frozen until assayed. Samples are currently being collected from human volunteers to compare to park samples. It is anticipated that more park samples will be required due to poor growth of several bacterial colony types upon secondary propagation.

Project title: **Analysis of a Eukaryotic Microbial Mat Community across Environmental Gradients in a Thermal Acidic Stream**

Principal investigator: Dr. Joan Henson
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Lewis 109
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Bozeman, MT 59717

Additional investigators: Michael Ferris, Kathy Sheehan, Keith Cooksey

Objective: To investigate the eukaryotic genetic diversity, ecophysiology, and behavior of a mat community in Nymph Creek using contemporary molecular analysis and microscopic methods with particular interest in the interaction between *C. caldarium* (a single-celled alga) and *D. constricta* (a filamentous fungus).

Findings: Preliminary microscopic examination has begun. PCR clone libraries are being investigated.

Project title: **Comparative Study of Sulfur-Turf Microbial Mats between Japanese Hot Springs and Yellowstone**

Principal investigator: Dr. Kenji Kato
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Shinshu University
Matsumoto 390-8621
Japan

Additional investigators: Hiroyuki Yamamoto, Yunosuke Maki

Objective: To evaluate the genetic difference between the bacteria in Japanese sulfur-turf and those in Yellowstone's. Sulfur-turfs exist in hot spring water effluent when the temperature exceeds 50° C and the water contains a significant amount of hydrogen sulfide. From analysis of small sub-unit rRNA of sulfur-turf taken from Japanese hot springs, we found that sulfur-turf bacteria are genetically very ancient. Thus, knowing the genetic difference between Japanese sulfur-turf bacteria and those of Yellowstone is an exciting subject, which will lead to an idea of the cause of biodiversity and evolution.

Findings: We found sulfur-turf-like bacteria from two sites in Yellowstone and started to analyze their genetic similarity with Japanese sulfur-turf bacteria. We are continuing the analysis.

Project title: **Population Biology of *Sulfolobus* spp. in Acidic Hydrothermal Environments**

Principal investigator: Dr. Brian Kinkle
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Additional investigators: Dennis Grogan

Objective: 1) To isolate and characterize anaerobic, pyrite-forming bacteria. 2) To isolate and characterize thermophilic, acidophilic archaea.

Findings: We have isolated several Gram-positive and Gram-negative bacterial strains capable of anaerobic formation of pyrite. We are currently characterizing the physiology of these strains and the minerological effects of its activities. In addition, we have isolated, characterized, and archived numerous thermophilic, acidolophilic archaea and are currently designing molecular criteria for differentiating among them.

Project title: **Microbial Biotransformations and Ecology**

Principal investigator: Dr. Charles Kulpa
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University of Notre Dame
Notre Dame, IN 46556

Additional investigators: Mark A. Schneegurt, Sophia Y. Dore

Objective: To isolate microorganisms with unique metabolic activities allowing for the transformation of polycyclic aromatic compounds that may contain heterocyclic rings and related products from the petroleum industry.

Findings: Samples obtained from the park in July 1999 have been used as inocula for enrichment cultures. The compounds of interest were provided as sole carbon, energy, or sulfur sources. Cultures were maintained aerobically under mesophilic or thermophilic conditions using a variety of media. Selection of interesting organisms from the enrichment cultures will continue through 2000. Soil

samples taken for analysis of microbial community structures in hot spring sediments have yet to be studied and remain in a freezer repository. A few soil samples have been included in a survey of soils used for testing DNA extraction procedures. Two roadside soil samples are being tested for platinum group elements. New enrichment cultures may be started if fresh inocula are obtained in 2000.

Project title: **Bacterial Diversity of Thermophilic Photosynthetic Bacteria**

Principal investigator: Dr. Michael T. Madigan
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Objective: The main objective of this research is to discover and isolate laboratory cultures of anoxygenic (non oxygen-evolving) photosynthetic bacteria from thermal environments. Photosynthetic bacteria are model organisms for the study of basic problems in photosynthesis, and thermophilic phototrophs are very desirable because of their thermostable photosynthetic machinery. The long-term goal of the research is to probe photosynthetic diversity in hot springs of various chemistries and temperatures to determine the physiochemical limits to photosynthesis. This includes isolating and characterizing new species of photosynthetic bacteria and studying their basic biological properties including physiology, biochemistry, and phylogenetic position in laboratory cultures. All cultures of thermophilic phototrophs from Yellowstone as well as New Zealand thermal springs have been deposited in the American Type Culture Collection (ATCC) for public access by any qualified individual. This is basic research; no commercial funding or research ties exist between this project and any for-profit organization.

Findings: No sampling was done in Yellowstone National Park during calendar year 1999. However, hot springs were sampled in Rotorua, New Zealand. These are springs that contain the thermophilic green sulfur bacterium *Chlorobium tepidum*. Previous searches for strains of this organism in YNP have been unsuccessful. However, using specific enrichment culture protocols that have been successful with New Zealand samples, we continue attempts to document this photosynthetic bacterium in microbial mats that form in high sulfide, slightly acidic hot springs in YNP, such as those in the Mammoth Upper Terraces region. Work also continues on the development of specific nucleic acid probes for use in surveying hot spring microbial mats for the presence of all four major groups of photosynthetic bacteria.

Project title:	**A Molecular Analysis of the Microbial Diversity present in the Greater Yellowstone Ecosystem**
Principal investigator:	Dr. Eric Mathur
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Address:	Diversa Corporation 10665 Sorrento Valley Road San Diego, CA 92121
Additional investigators:	Martin Keller, Jay Short, Terrance Bruggeman

Objective: Diversa's research efforts are directed towards gaining a better understanding of the microbial diversity present within Yellowstone National Park; coupled with this molecular taxonomic survey, Diversa scientists will employ recombinant techniques to screen environmental samples for relevant biomolecules. Attempts will then be made to correlate phylogenetic and catalytic diversity.

Findings: During FY97, Diversa scientists collected environmental samples from the following regions within Yellowstone: Heart Lake, Norris Geyser Basin, Octopus Springs, Five Sister Springs and Obsidian Pool. Nucleic acids were isolated from many of these samples and some have been captured in the form of 16S and environmental DNA libraries. Work in progress includes sequencing of unique 16S clones and construction of phylogenetic trees, as well as ongoing screening of the environmental libraries for clones expressing a variety of enzymatic activities.

Project title:	**An Analysis of Soil Microbial Community Structure in an Evolving Thermal Soil Environment**
Principal investigator:	Dr. Timothy McDermott
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Address:	Montana State University Department of LRES 334 Leon Johnson Hall Bozeman, MT 59717
Additional investigators:	Tracy Norris, Jon Wraith

Objective: The objective of this work is to use molecular methods to analyze soil microbial community succession in response to changes in soil temperature. Investigations of the biology of hydrothermal systems have added greatly to our understanding of microbial species diversity and their evolutionary relationships. However, previous studies have generally been limited to thermal systems that are well established on the time scale of human observation. The death of lodgepole pines in this study site is

indicative of a very recent expansion of the underlying geothermal plumbing. In some places temperatures as high as 80º C were recorded, which only six months previously were closer to 25º C. This study site provides us with a unique opportunity to observe changes in microbial community structure as they occur. This work will allow us to address questions concerning the forces affecting microbial community structure, diversity, and the colonization of geothermal features by thermophilic microorganisms.

Findings: A research plot was designated and thermocouple probes were inserted in the ground at specific locations within the plot to measure soil temperature at regular intervals. Temperature data collection was initiated in November 1999. Results indicate that the research plot includes an area of expanding geothermal activity. Soil samples were collected at several sites within the research area. Extraction of nucleic acids (DNA and RNA) from these samples by conventional protocols is underway in the lab. The DNA extracted from soil samples was PCR (polymerase chain reaction) amplified using primers specific for ribosomal gene sequences of bacteria. The PCR products were then subjected to Denaturing Gradient Gel Electrophoresis (DGGE) to compare the bacterial diversity of the sampling sites. Each band on a DGGE gel represents a unique DNA sequence, which in theory corresponds to a unique organismal species. Initial results suggest that temperature has been a selective force in thermally impacted soils as evidenced by apparent reduced species diversity from these sites.

Project title:	**Characterization of the Microbial Rhizosphere Population of Acid and Thermotolerant Grasses associated with Hot Springs and Microbial Diversity in Thermal Soils in YNP**
Principal investigator:	Dr. Timothy McDermott
Phone number:	See previous entry
Additional investigators:	B. Inskeep, M. Burr, M. Young, L. Botero

Objective: To study the diversity and identification of the thermophilic and acidophilic organisms associated with thermophilic plants located in YNP. We are also very interested in examining the diversity of the microbial community that thrives in select thermal soil locations.

Findings: We have obtained molecular evidence that some thermal soils (65°C to 85°C) apparently have diverse and complex prokaryotic communities. One pure culture isolate appears to represent a new taxonomic division. This study is continuing as we are developing new culturing techniques to cultivate maximal numbers of different prokaryotes from these soils. Physiological and biochemical characterization of these different isolates will then follow. Minimal soil disturbance has occurred; typically we use one gram of soil for each experiment.

Project title: **Microbiology of Hot Acid Springs**

Principal investigator: Dr. Gregory Olson
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Suite B
Golden, CO 80403

Objective: No work was done during 1999

Findings: No work was done during 1999

Project title: **Phylogenetic Analysis of High-Temperature Ecosystems**

Principal investigator: Dr. Norman Pace
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Department of Molecular, Cellular and Developmental Biology
Campus Box 347
Boulder, CO 80309

Additional investigators: Carrine Blank, J. Kirk Harris, John R. Spear, Jeff Walker

Objective: Ongoing research within the park is founded on surveying microorganisms in various Yellowstone microbial ecosystems with varying solution chemistries. A molecular approach employing the analysis of the small sub-unit 16S rRNA ribosomal gene is used to determine what microbial members are present in these ecosystems. To accomplish this task, ongoing studies include analysis of both sub-aqueous and sub-aerial systems for bacterial, archaeal, and eukarial life.

Findings: Survey of microorganisms associated with geothermally produced siliceous sinters (e.g., Octopus Spring, Queens Laundry): Seven high-temperature (90-96° C) silica depositing springs throughout Yellowstone have been examined. In addition, the communities in different microenvironments (associated with spicular geyserite at the air-water interface and sub-aqueous strataform geyserite) have been compared in order to better understand how microorganisms may influence the deposition of silica. This work is in collaboration with Sherry Cady of Portland State University.

Survey of eukaryotes (eukaryotes are distinguished from bacteria and archaea by having a membrane bound nucleus) in anaerobic, low temperature environments: These anaerobic eukaryotes are displaying large diversity in the lower temperature environments, in the range of new genera to kingdoms. Such work with this domain of life that plants and animals are members of has never been done.

Novel Bacterial Lineages: Discovered the occurrence of novel bacterial phyogenetic divisions through molecular biological analysis from samples obtained within the park. A paper submitted to *Applied and Environmental Microbiology* describes two unique bacterial 16S rRNA gene sequences obtained from a dark green microbial mat on the northwest side of Black Hole in the White Creek Group. A third sequence obtained from the Obsidian Pool hot spring is also described. All three sequences have been deposited in GenBank. If accepted, the paper will be published in mid-2000. These sequences add to the greater body of knowledge about what types of bacteria occur in Yellowstone National Park.

High Temperature Limit of Life: Currently, the highest temperature limit for life is 113° C. A hot-water-filled, 250-foot deep well drilled in the 1960s in Biscuit Basin, Well Y-7, is currently being surveyed for the possible upper temperature limit of life. The well's water is 47° C at the surface. Glass slides and/or cotton fiber have been suspended at various depths down the length of the well on a stainless steel cable for varying amounts of time. We have found bacterial and archaeal cells up to 95° C. Ongoing work may push this temperature higher. The Park Service maintains the well under lock. The well is in a public location, requiring ranger assistance for both access and interpretation for this ongoing work.

Life in Cinder Pool, Norris Geyser Basin: Cinder Pool is a unique geothermal feature in the world within the Norris Geyser Basin. The pool has been geochemically well-described by others, but as yet, not biologically described. To do so, both cotton and fiberglass growth surfaces were hung in the 88° C Cinder Pool, at both the surface and two meters down, for approximately one month to allow for cellular adhesion. The fibers were removed and brought back to the lab for subsequent DNA extraction and molecular phylogenetic work-up. To date, with a limited number of molecular primers applied, a limited amount of diversity appears to be present. Such work will add to what is known about what kinds of microorganisms are capable of living in these extreme and unique environments.

Project title: **Exosporial Membrane Characteristics of Thermophilic *Clostridia***

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Additional investigators: George T. Tortora, John B. Warren

Objective: To culture samples collected from Terrace Spring and Beryl Spring, isolate and subculture endospore-forming thermophilic bacteria. To identify the temperature at which growth is optimized. To characterize specific colonies by light microscopy, histochemistry, transmission and scanning electron microscopy.

Findings: We isolated seven different organisms based on colony type and temperature preference. All of the spores were found to have a ruthenium red-osmium positive outer covering (exosporium?), which may represent glycopeptide associated with attachment phenomena (glycocalyx). Extensive protein containing extracellular network attached some anaerobic species to one another and the substrate, effectively forming a tenacious matrix. This protein seems to be formed within the spore envelope and is liberated upon out-growth of the newly formed vegetative cell. Therefore, the newly released bacterial cells have a protective meshwork for attachment.

Project title: **Ecology of Microbial Phototrophs in Extreme Environments-Thermal and High Iron**

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Additional investigators: Niki Parenteau, Victor Scopa, Kirstin Lightfoot

Objective: To determine the role of photosynthetic prokaryotes in thermal habitats and specifically in high iron thermal habitats. To determine the effects of iron on photosynthesis in cyanobacteria and anoxygenic phototrophs in hot spring mats.

Findings: Enrichment cultures have revealed evidence for the presence of purple photosynthetic bacteria that may be photoferrotrophs in the high iron sediments of Chocolate Pots Hot Springs. Very high iron stimulated photosynthetic rates in the *Synechococcus* and *Chlorofexus* mats suggest possible photoferrotrophy in the *Synechococcus* or *Chloroflexus*. Electron microscopy revealed that cyanobacteria are encrusted in iron in these springs. CLSM showed that filamentous prokaryotes bind and trap the iron sediments. A culture of *Chloroflexus* has been obtained from the highest temperature mats at Chocolate Pots. Preliminary experiments have shown no stimulation by iron in this culture. Work continues on the nature of iron stimulation of photosynthesis in the high temperature mats.

Project title: **Isolation and Characterization of Thermophilic Microorganisms**

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Objective: To determine the presence and ecological significance of the population of thermophilic microorganisms of the greater Yellowstone Ecosystem. To obtain additional thermophilic microorganisms for microbial and biochemical studies including the purificaion and characterization of thermostable enzymes.

Findings: A brief 1999 collection visit was made to Yellowstone (July 12-16) to obtain annual population samples from Obsidian Spring and nearby springs, and obtain several small "pink filament" samples from the runoff channel of Octopus Spring. The 1999 Obsidian samples again resulted in the isolation of a slowly growing, facultative anaerobic, spore forming bacterium which forms extremely swollen terminal spores (nicknamed doorknob). These isolates (*Moorella obsidium*) are similar (but not idential) to *Moorella glycerini* isolated from Calcite Springs and *Thermoaerobacter marianese* recently isolated from the world's deepest sea floor (Marian Trench). In additional to the usual aerobic microbial isolates from Obsidian, the 1999 samples also showed a modest level of isolates similar to *Thermomicrobium rosium*.

Project title: **Geochemical Constraints on the Ecology of the Deep Lineages within the Bacteria and Archaea**

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Additional investigators: Everett Shock, Cristina Takacs

Objective: 1) Determine the microbial diversity and geochemistry associated with high temperature thermal springs in YNP. 2) Study the ecology of microbial communities inhabiting YNP thermal springs.

Findings: Our research in 1999 focused on Calcite Springs and Obsidian Pool. We collected extensive geochemical and molecular biological samples along chemical and physical gradients in the springs. Additionally, enrichment culture techniques were used to isolate novel thermophilic microorganisms. Initial results indicate that the geochemistry and community structure of the springs is dynamic on a spatial and temporal scale. Our research in 2000 will focus on linking geochemical and community differences and using our cultures to understand the physiological diversity of Calcite Springs and Obsidian Pool.

Project title:	**Analysis of Metal Resistance in Yellowstone Bacteria**
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Additional investigators:	Barrie Johnson, Simon Silver, Mark Delwiche, Heather Silverman

Objective: Identify and characterize heavy metal resistant bacteria from thermal features within YNP.

Findings: This year's sampling focused on the Norris area. Samples were obtained near Realgar Springs, north of the main Norris geyser basin, and south of the main Norris area near Tantalus Spring. Enrichments were performed to recover *Sulfolobus acidocaldarius* growing autotrophically. Only *Acidianus brierleyi* and *Metallosphaera sedula* were recovered under these conditions. It appears that recently published information indicating *S. acidocaldarius* is a heterotroph *only* may be correct. New techniques for cultivating *Sulfolobus* were obtained from Dr. Wolfram Zillig's laboratory in Germany, and are now being employed by our group and that of Dr. Mark Young at Montana State University. 16S rDNA analysis confirms physiological testing, but also indicates the possible presence of *Sulfolobus solfataricus* in the samples.

Project title: **Genetic Analysis of Brucella from Bison and the Generation of a PCR-Based Diagnostic System for Epidemiological and Ecological Studies**

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Additional investigators: Regina Redman, Frank Roberto

Objective: The objectives of this work are to: 1) Determine the genetic complexity of *Brucella* isolates from a variety of animal hosts. 2) Develop a high sensitivity PCR-based diagnostic system to identify the presence of *Brucella* isolates. 3) Develop a PCR-based diagnostic system to track specific genotypes of the *Brucella* isolates. 4) Develop a PCR-based diagnostic system to discriminate live *Brucella* cells from dead cells. In addition to the objectives listed above, studies will be performed to convert the diagnostic systems to field adaptable systems capable of simple and rapid data generation.

Findings: We have completed the genetic analysis of *Brucella* isolates from several animal hosts, including bison, cattle, and elk. These data are currently being incorporated into a scientific manuscript. In addition, several PCR primer sets have been prepared that amplify products specifically from *Brucella abortus* isolates. Protocols have been developed for extracting *Brucella* cells from blood samples and detection using the PCR diagnostic system. This year, genotype-specific PCR primer sets will be generated for tracking isolates in the field and studies will begin to establish a diagnostic system to differentiate live and dead cells.

Project title: **Ecology, Physiology and Evolution of Microbes**

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Objective: The objective of this project is to study diurnal patterns of organismal physiology (e.g., photosynthesis, DNA synthesis) in order to better understand evolution on early Earth and the way organisms function in their environment today. Specifically, in 1999 the focus was on the effect of naturally occurring DNA damaging agents on DNA synthesis rates.

Findings: In 1999 research focused on the effects of UV radiation and hydrogen peroxide on microbial mat communities in the Norris Geyser Basin. We found that UV radiation enhances DNA synthesis rates during the day, which we interpret as being indicative of excision repair. However, previous work suggests that the damage may be due to UVA effects mediated through oxidative damage rather than the direct effect of UVB. Experiments adding hydrogen peroxide to samples, done in collaboration with Cindy Wilson, showed an increase in DNA synthesis in response to small amounts of additional hydrogen peroxide, and a decrease in response to high levels. *Zygogonium* mats that were placed under UV opaque screens from July to September showed a down regulation in DNA synthesis when finally exposed to solar radiation in contrast to an adjacent mat that had been left exposed to full solar radiation. These studies will be repeated and extended in 2000.

Project title:	**Isolation, Identification, and Characterization of Microorganisms Living in Extreme Environments**
Principal investigator:	Dr. Perry Russell
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Objective: There are two main project objectives. One is the training and inspiring of undergraduate students in the field of microbiology. Secondly, identification and characterization of the many unidentified and novel microorganisms associated with the thermal features in Yellowstone National Park.

Findings: There have been no further results from this study for the year 1999. Two morphologically different bacterial colonies initially grew on a very minimal agar media at higher temperatures. However, by the time these samples were returned to the laboratory in Kentucky for further characterization, the organisms were no longer growing and there were no survivors. However, I was able to obtain one of my objectives by having a student with me who was able to observe and learn something about sampling techniques and laboratory techniques in molecular biology. All of the samples I obtained from the park were consumed and I will return again in the summer of 2000 to obtain more samples.

Project title: **Subsurface Transport Mechanisms for High-Temperature Microbial Life and the Nature of the Subsurface Biosphere**

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Objective: Determination of the transport mechanisms and the three-dimensional structure of thermophilic and hyperthermophilic microbial communities. The work is done in relationship to the structure(s) of the thermal intervals and isotherms of their optimal temperature range and limiting temperatures.

Findings: Finite-element numerical simulations have been completed for the determination of the flow velocity vectors and the thermal structure of theoretical end-member microbial transport scenarios. These include: 1) continuous convective transport of microbes in fracture and microporous volcanic rock; 2) continuous convective transport in multiply-fractured volcanic rock.

Project title: ***Pantoea Agglomerans* and Other Epiphytic Bacteria of Grasses in Yellowstone National Park**

Principal investigator: Dr. David Sands
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Additional investigators: David Pascual, Alice Pilgeram, Tim Anderson, Laura Carsten

Objective: Vaccinating mammals to induce immunization has proven to be effective in the past when using common syringe and needle methods. However, with the increasing threat of feral animals transmitting disease to domestic livestock, novel vaccine delivery systems may be more effective for inoculation of wild species in their natural environment. Brucellosis is a disease that causes fetal abortions and, according to serological testing, infects 48% of bison and 1% of elk in Yellowstone National Park and 76% of bison and 50% of elk in neighboring Grand Teton National Park. *Brucella abortus* poses an economic threat to the U.S. livestock industry. Although interspecies transmission of Brucellosis in nature has yet to be proven, the phenomenon has been demonstrated in laboratory settings. The implications are significant because, if even a single cow is infected, slaughter of all *B. abortus* reactive

animals in the herd is mandated - regardless of whether they actually have the disease. This potential loss could significantly impact Montana's economy. This research project is focused on adapting common plant epiphytic bacteria to carry antigens that will confer immunity to brucellosis via the mucosal route.

Findings: Grass samples from several areas in northern Yellowstone park were screened for commonly occurring epiphytes throughout the summer. Several common species of bacteria were identified using this method. Of these, five were chosen as test species (*Pantoea agglomerans*, *Pseudomonas putida*, *Rahnella aquatilis*, *Hafnia alvei*, and *Pseudomonas syringae* pv. syringae). Currently, little is known about the specific immune responses elicited by bison. However, the protein K99 is known to stimulate mucosal immunity in these animals. The five species of bacteria listed above were genetically modified to express the K99 protein. Currently, tests are underway to confirm that these modified bacteria can still compete with native bacteria found on leaf surfaces. In addition, mice have been dosed with the modified bacteria to determine the efficacy of the strategy.

Development of this novel delivery system has promising implications beyond bison inoculation. The system could provide an inexpensive way to inoculate domestic cattle against a wide range of diseases by spraying the product on hay or pasture grasses. This project is one of the first attempts to utilize microorganisms to immunize animals in their natural environment.

Project title:	**Diversity and Habitat Range of Sulfate-Reducing Microorganisms**
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Additional investigators:	David Ward, Nancy Hinman, Susan Fishbain, Alakendra Roychoudhury, Brad Jackson

Objective: We have analyzed samples from a number of different regions throughout the park. Sites include Bath Lake Vista, New Pit Spring, and Roland's Well Spring within the Mammoth Hot Springs region; Octopus and Mushroom Springs; two sites at the Nymph Creek area denoted as Nymph Creek and Black Sediment Pool; four sites in the Washburn region denoted as Site A, B, Acid Inkpot and Inkpot; five sites at Norris 100 Springs Plain denoted as Sites C, D, E, Cinder and Black Spring; and Obsidian Pool and Moose Pool in the Mud Volcano area. These sites provide a wide range of temperature and pH gradients (38°-90° C; pH 2-8). Significant rates of reduction were observed at Site C, Obsidian Pool, Nymph Creek, and Black Sediment Pool. We have established sulfate-reducing enrich-

ment cultures from the microbial mats of the Mammoth Hot Springs region. Stable enrichments were developed from New Pit Spring (H_2/acetate as substrates) and from Bath Lake Vista (acetate) and Roland's Well Springs (acetate). The DSR genes were amplified from each of the enrichment cultures using the DSR1F-DSR4R primer pair and cloned (pCRII vector) for sequence determination. We have also initiated enrichments from Obsidian and Black Sediment pools that demonstrate sulfate-reducing activity. We are currently analyzing these enrichments to determine if the organisms active in laboratory cultures are comparable to those identified by direct sequencing.

Findings: Our research at Yellowstone National Park has focused on better defining the diversity of sulfate-reducing bacteria along environmental gradients of pH and temperature. Organisms having the capacity to respire sulfate drive a key step in the global cycling of sulfur and are likely an important biological presence in many of the sulfur-rich geothermal areas within Yellowstone National Park. A long-term objective is to better define the environmental limits of dissimilatory sulfate reduction. Our primary method of assessing population diversity has been comparative sequence analysis of the highly conserved dissimilatory sulfite reductase (DSR) gene. This gene can be selectively amplified from DNA recovered from site material using PCR, as reported by our research group. Comparative sequencing of cloned DSR genes avoids the usual biases associated with culture-based methods of characterization. We have complemented this molecular characterization with on-site measurements of sulfate respiration in order to relate gene presence to corresponding environmental activity. We are also using more traditional culture-based methods to analyze cultivable sulfate-reducing bacteria. The recovery of deeply-diverging phylogenetic lineages, as defined by DSR gene sequence divergence, suggests that our current understanding of this important functional group of microorganisms is incomplete. Our combined analyses suggest that sulfate respiration is an important biogeochemical process in many of Yellowstone's geothermal features.

Project title:	**Isolation of New Hyperthermophiles and Investigations of Hyperthermophilic Bioptopes**
Principal investigator:	Dr. Karl Stetter
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Additional investigators:	Robert Huber, Wolfgang Eder, Gudrun Amann, Manuela Baumgartner

Objective: Isolation of new hyperthermophiles and investigations of hyperthermophilic biotopes.

Findings: A member of the novel kingdom Korarcheaota, identified by 16S rRNA gene sequence

analysis, collected from Obsidian Pool, has been grown in a continuous lab culture at 85° C in our institute. Comparative PCR amplifications of SSU rRNA gene sequences from this culture indicated substantial preferential PCR amplification of pJP27 sequences with korarchaeote-specific PCR primers.

Project title:	**Integrated Biogeochemical Database**
Principal investigator:	Dr. Daphne Stoner
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Additional investigators:	Ronald Rope

Objective: The objective of this multiple year project is to develop an integrated relational database and Geographic Information System (GIS) for mapping biodiversity data and associated geochemical and hydrological attributes in extreme environments.

Findings: The prototype data management system was completed and launched on the Internet. The database for housing and managing field and reported (citations) data for thermophilic microorganisms and geyser/hot springs characteristics was revised. Fields for temporal and spatial (mapping) data were developed as well as links to photographs and output field forms for field data and query reports. Draft standard field protocols and safety analysis for characterizing thermal features were developed.

Project title:	**Development of Harsh Environment Biosensors**
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Additional investigators:	Diane Key, William Apel, William Keener, Frank Roberto

Objective: The objective of this project is to culture thermophilic microorganisms from Yellowstone hot springs. These organisms will then be tested for the presence of various enzymatic activities and the enzymes will be isolated and purified from organisms that show large amounts of activity. The enzymes will be studied to determine how high temperatures affect their characteristics and compared to low temperature versions of the enzymes.

Findings: Two sampling trips were taken to YNP this summer on June 9 and July 21. Water and microbial mats were collected from Firehole Pool, Twin Vista Butte Springs, Octopus Springs, Spring LNN2, and from the Hot Lake area. The samples were inoculated into liquid and solid minimal salts medium containing lactate as the carbon source and incubated at 70° C for up to four weeks. Nineteen organisms were isolated from the samples and characterized as Gram + and - rods. Additional samples were incubated under denitrifying conditions with collaborators at Washington State University. No organisms were isolated under those conditions. Samples were inoculated into minimal media containing amides and ammonium nitrate. Three uncharacterized strains have been isolated under these conditions.

Project title: **Search for the Upper Temperature Limit of Eukarotic Life**

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Additional investigators: Susanne J. Trent, Fred Martwick, John Hines

Objective: Search for multi-cellular organisms living at high temperatures using video cameras equipped with macro-lenses and configured to hold "bait" in view with the objective of attracting these organisms into the field of view. This search requires meeting the following objectives: 1) Construct a compact video camera system that can cope with high temperatures (up to 90° C) and pH down to 1.0. 2) Assemble cameras into an array that will allow the temperature, pH, and depth to be monitored in the vicinity of the camera. 3) Field test the system for deployment in remote sampling areas (transported in backpacks).

Findings: Our first year saw the successful construction of a video camera system that was field tested at a variety of sites in Yellowstone National Park. Two small video cameras built by DeepSea Power and Light (normally used for investigating plumbing) were capable of withstanding temperatures of up to 120° C for one hour with noticeable, but acceptable degradation of the image. A probe, consisting of two cameras (one macro and one wide angle), lights on each camera, a versatile bait holder, and temperature, pH, and depth sensors, was fabricated out of Delran. The probe has 30 meters of cable and was supported by a data acquisition system attached to a backpack frame. The complete system weighed about 150 lbs. and could be carried by three hikers with large backpacks. It was deployed at a variety of sites in Yellowstone, ranging from Rabbit Creek (32° C) to Cinder Pool (120° C). Cameras and depth sensor worked well but the temperature and pH sensors failed. In Rabbit Creek, we observed Caddisfly larvae (*Heliopsyche borealis*), fly larvae (blood worms), and ostracods. Underwater video of hot springs was made available and televised on national television.

Project title: **Ecology of Hot Spring Microbial Communities**

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Additional investigators: Mary Bateson, Thane Papke, Mike Ferris, Uli Nuebel

Objective: The general objective of our research is to understand the distribution and activity of microorganisms inhabiting microbial mat communities in geothermal effluents. At the moment, we are particularly interested in understanding the composition, structure, and physiology of these mat communities, as models of microbial communities in general. We are using ribosomal RNA (rRNA), intervening transcribed spacer (ITS), and lipid biochemical cell components to identify community members. Our work relates to evolutionary microbiology in the sense that these gene sequences give phylogenetic information, and the association of lipids with their microbial sources helps us interpret the chemical fossil record produced by organic geochemists. In addition, we are attempting to evaluate whether the stable carbon isotope ratios of specific lipid biomarkers might help distinguish modern mat communities constructed by either cyanobacteria or green nonsulfur bacteria and hence their stromatolite counterparts in the fossil record.

Findings: During 1999, we made the following major observations: Cyanobacteria: *Synechococcus* populations in Mushroom Springs show a similar temperature distribution to that in Octopus Springs. We are currently examining their vertical distribution at four temperature-defined sites where we characterized light and chemical parameters using microsensors (Kühl). We succeeded in cultivating 5 to 10% of the *Synechococcus* cells that are apparently genetically dominant populations and are pursuing the rest as well as studying their adaptations to light and temperature. We have demonstrated that genetically unique *Synechococcus* occur in hot springs around the world and even within Yellowstone.

Green nonsulfur bacteria: We used rRNA probes to demonstrate that the organisms contributing type-C 16S rRNA sequences in mat communities are filamentous and we are proceeding to evaluate their metabolisms through combined probing and microautoradiography and/or microscope spectrophotometry. We have continued experiments to evaluate the autotrophic metabolism of green nonsulfur bacteria by 1) using microsensors (Kühl) to demonstrate that the potential electron donors hydrogen and sulfide occur in the photic zone of mats containing cyanobacteria and green nonsulfur bacteria (i.e., Mushroom Springs and Tangerine Springs) in the morning and evening; and 2) conducting further 13C labeling studies at such times of day.

ORNITHOLOGY

Project title: **Movements and Survival of Bald Eagles produced in Yellowstone**

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Additional investigators: George J. Montopol, Peter Harmata

Objective: Determine movements, survival, and turnover of bald eagles produced and nesting in Yellowstone National Park.

Findings: Movements and survival of immature bald eagles (*Haliaeetus leucocephalus*) beyond their first winter remain largely unknown and lack of information may impede strategies for effective conservation. We analyzed encounters, sightings, and radio detections of bald eagles auxiliary marked as nestlings in the Greater Yellowstone Ecosystem between June 1979 and July 1997 to determine movements, survival, and the role of Yellowstone National Park in the ecology of GYE bald eagles. Of 344 bald eagles banded, 17% were encountered to June 1998. Most (84%) were encounters of bald eagles greater than one year old. Half of encounters were external to the GYE and occurred in seven western states and one Canadian province. All sightings of color-banded bald eagles (n=76) were of bald eagles greater than one year old, and 76% occurred in the GYE. Location and timing of encounters and detections of radiotagged bald eagles indicated most (more than 90%) juveniles left the GYE in autumn, traveled as far west as coastal states to winter, and returned to natal areas the following spring. Natal dispersal appeared female-biased, and bald eagles produced in the GYE recruited into breeding populations both in and out of the ecosystem. Mortality of 49 bald eagles recovered was from unknown causes (31%), electrocution or collision with power lines (20%), known or suspected poisoning (16%), and gunshot wounds (14%). Eighteen percent was distributed among three other causes. Recovery rates indicated bald eagles 3-5 years old experienced the highest mortality. Kaplan-Meir analysis of detections of radiotagged bald eagles indicated first-year survival of 87%, followed by a constant decrease in survival rate over seven years. Survival estimates determined by radiotracking were consistent with band recovery results in illustrating low survival in 3-5 year old age classes. Radiotracking of immature bald eagles suggested habitat in Yellowstone National Park was important in promoting survival of eventual recruits to the GYE population.

PALEONTOLOGY

Project title:	**Depositional Micro-Environments and Preservation Potential of Plants and Arthropods in Recent and Fossil Hot Spring Systems**
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Additional investigators:	Nigel H. Trewin, Alan Channing

Objective: Recent discoveries of exceptionally preserved early terrestrial plants and animals from the Early Devonian (400 Ma old) Rhynie chert hot spring complex (Aberdeenshire, Scotland, UK) has revealed the potential for exceptional fossilization (including soft tissues) within hot spring systems. The Rhynie complex consists of at least two separate vents, one of which exhibits geyserite splash texture. The current project extends the scope of the study to include recent silica-depositing systems within Yellowstone National Park as analogs for this fossil example. Collections of silica encrusted and silica entombed arthropods (primarily insects) will be examined alongside pre-existing water chemistry data and the geometry and topography of the hosting geothermal features to reveal processes involved in the entrapment and fossilization of organic debris.

Findings: Initial fieldwork during late August 1999 revealed the presence of three geothermal features capable of preserving organic remains: Medusa Spring, Opalescent Spring, and Porkchop Geyser, all within the bounds of the Norris Geyser Basin. The three systems varied markedly in water chemistry, topography, activity, and outflow geometries, revealing complexity behind fossil preservation in hot spring systems. Silicified arthropods collected were dominated by dragonflies and moths. Ground dwelling fauna were represented by crickets and rare arachnids. Preservation often took the form of irregular siliceous concretions or "biscuits" with an organic nucleus formed due to repeated immersion of the object in silica-laden waters.

Project title: **Dendrochronology in the Yellowstone Fossil Forest**

Principal investigator: Dr. Michael Arct
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Objective: Map petrified wood localities and interpret ecological and depositional histories of various fossil forests using: 1) annual growth ring series (cross-identification, standard descriptive statistics, tree age determinations); 2) taxonomy; 3) taphonomy; and 4) rock descriptions. Most recently, attempts have been made to use botanical features from specific horizons at the Specimen Creek locality to determine stratigraphically equivalent horizons at an exposure 1.3 km to the southeast.

Findings: Fieldwork was conducted at the Specimen Creek 2B exposure on September 26 and 27. Data were collected from 24 stumps. No specimens were collected. Poor weather limited work time.

Project title: **Silicification of Higher Plants in Hot Spring Environments**

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Additional investigators: Alan Channing

Objective: 1) Assess the possible environments of higher plant silicification, burial, and diagenetic alteration associated with surface geothermal activity. 2) Investigate the extent and nature of silica mineralization within plant material of hot spring environments. 3) Determine physicochemical, biochemical, and physiological controls on silica permineralization at cellular to structural levels. 4) Compare silica fabrics from Yellowstone plants, sub-fossils, and fossils with those of a 400 million-year-old fossil hot spring deposit at Rhynie, Aberdeenshire, Scotland. 5) Investigate the physiological adaptations of modem plants to the sedimentary, hydrogeological, and geochemical regimes of modern hot springs and assess the probability of similar adaptive strategies in early terrestrial ecosystems. 6) Assess using in vivo and in vitro experimentation rates and sequences of silica mineralization within plants and plant organs commonly found in Yellowstone sub-fossil sinters.

Findings: 1) SEM observation of plant material displaying incipient silica mineralization provides evidence of intracellular nucleation, polymerisation, and aggregation of sub-micron spheres via colloidal

mechanisms. Infilling of intercellular voids occurs rapidly. Rigid silica-particle frameworks form during the first 12 months of immersion. 2) Silica deposition fabrics and the degradation of plant materials are mediated by the interplay between a suite of physicochemical parameters (notably pH, temperature, cation concentration) and microbial decomposition. Reduction or cessation of fungal activity by hot fluids promote exceptional preservation. 3) Rapid vertical, lateral, and temporal variation in substrate/groundwater temperature, moisture, and geochemistry indicate a degree of tolerance to those conditions in colonizing plants. Plant dissemules, xerophytes, halophytes, and aquatics occupy and are silicified within definable hot spring sedimentary facies.

Project title:	**Paleontological Survey of Yellowstone National Park**
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Additional investigators:	Vince Santucci

Objective: To develop a database of the fossil resources within Yellowstone National Park.

Findings: A significant amount of preliminary work has been accomplished. Vince Santucci has already published on the Internet (*http://www2.nature.nps.gov/grd/geology/paleo/yell_survey/index.htm*) our current knowledge about the paleontology of Yellowstone National Park. A manuscript on Eocene mammals from Yellowstone is in progress.

RECREATION

Project title:	**Interpretive Impacts from the Participants' Perspectives**
Principal investigator:	Elizabeth Barrie
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Objective: The proposed study will investigate the nature and meaning of meaningful interpretive experiences by analyzing subjective accounts of recollected meaningful interpretive programs collected from visitors to two nationally significant interpretive sites. Studying the most meaningful interpretive encounters will provide insight into interpretation at its best for the participants. Based on the accounts of the informants in this study, a model of the elements of meaningful interpretive experiences will be developed which can be used to inform the creation and evaluation of interpretive

Findings: Two hundred visitors waiting to see Old Faithful erupt during the period from August 19 to August 21, 1999, provided the researcher with contact information (name, address, and phone number), signed informed consent statements, and received a copy of the informed consent statement. By December 31, 1999, phone interviews had been conducted with 40 of these subjects. The interviews are currently being transcribed. There has been no analysis done on these interviews yet.

Project title:	**The Evolving Social Construction of Wolves: Exploring Yellowstone National Park Visitors' Social Interactions with *Canis Lupis***
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Additional investigators:	Michael Patterson, Jessica Montag

Objective: This study explores visitors' perceptions of wolves, how these perceptions are shaped, the

nature of the wolf watching experience, and how these issues influence social conflict over wolf reintroduction and management. Using a social constructivist approach, this study is analyzing the in-depth interviews to explore: 1) the public's social constructions of wolves in various contexts; 2) the nature of the recreational experiences individuals seek with respect to wolves; 3) how current social conflicts are affecting public perceptions; and 4) how new opportunities to interact with reintroduced wolf populations affect people's perceptions of wolves in the future. The goal of the study is to identify and describe the range of experiences and meanings associated with wolf watching.

Findings: From July 1999 through September 1999, 21 in-depth interviews were completed. These interviews ranged from 10 minutes to one and a half hours long, with the average interview lasting between 30-40 minutes. Another 10 interviews are expected to be completed between January and March 2000. The interviews occur in the Lamar Valley, an area where wolf sightings are prevalent. Although analysis is ongoing, the nature of the insights that are being revealed include the dynamics of the wolf watching experience, the broader meanings of the Yellowstone wolves, and how this experience is incorporated into the participant's life and into the total Yellowstone National Park experience.

SOCIOLOGY

Project title:	**Visitor Understanding of Life in Hot Springs and Other Thermal Environments**
Principal investigator:	Dr. Michael J. Brody
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Address:	Reid Hall Department of Education Montana State University Bozeman, MT 59717
Additional investigators:	Warren Tomkiewicz, Charles J. Graves

Objective: Determine park visitors' understanding of geothermal features and associated organisms. Interview approximately 200 park visitors at Midway Geyser Basin.

Findings: This study investigated people's understanding of a new scientific theory concerning the evolution of life based on thermophilic bacteria and archaea found below the surface of the earth and the relevant correct concepts, missing concepts, and misunderstandings that people hold in relation to this new theory. Science educators are presently faced with a new and revolutionary theory, which holds that life originated on earth as a group of organisms preliminary to bacteria, plants, and animals. Yellowstone National Park contains more of the geothermal features that provide the environment for these organisms than all of the rest of the world combined. Yellowstone National Park is the site where the first organisms were identified, isolated, and then cultured for technological and biological applications. Researchers interviewed 191 visitors at Yellowstone National Park's Midway Geyser Basin concerning these geological features, the associated organisms, biological diversity, and the value of these ancient life forms. Results indicate several correct ideas, which can be used to help anchor new concepts in the understandings of people. A number of misconceptions regarding evolution and biological diversity were identified. Finally, people's values associated with conservation and utilization of biological resources in national parks are described. The implications of this study are global in that these microorganisms are found in various sites throughout the world. Further, environmental and science educators are now faced with teaching a completely different paradigm of the origin and evolution of life.

Project title:	**Close Encounters: Factors Affecting whether People Approach Animals Closely in a National Park**
Principal investigator:	Dr. Robert W. Colman
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Email:	*rwc@psu.edu*
Address:	315 Woodbine Street Harrisburg, PA 17110-1856

Objective: This multi-year project is designed to explore regularities in human behavior in "animal jams," with a particular focus on social influence processes in crowd settings.

Findings: No data were collected in 1999.

Project title:	**People and Nature: Yellowstone as Landscape**
Principal investigator:	Raymond Fenio
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Address:	9645 East State Road 45 Unionville, IN 47468

Objective: This research will provide an ethnographic study of a national park. The descriptive data provided by ethnography are not easily assembled by other methods. Living in a place and observing, as well as talking with the people who visit, work, and reside within it, provides a greater depth of understanding. In discovering what people do when they experience Yellowstone, what they expect and how these expectations shape their attitudes about parks, wilderness, and recreation, this research should provide a valuable contribution to park management and hopefully encourage and invite thoughtful dialogue over what culture and nature means and their relative value in emerging policy.

Findings: This research is ongoing. However, some interviews have been conducted with visitors and employees. Observations about what visitors actually do have been recorded but without any results or conclusions at this time.

Project title: **Pilgrims and Rituals in Yellowstone National Park: Touristic Encounters with the Sacred**

Principal investigator: Sandra Nykerk
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Gardiner, MT 59030

Additional investigators: Laurence Carucci

Objective: Examine relationship between visitors and perceptions of wilderness/nature as inculcated in Yellowstone National Park

Findings: Tourism, Yellowstone National Park, and the photograph are cultural productions co-constructed in a symbiotic relationship. Tourism and tourists function as consumers of a cultural ideal, manufactured from and manifested in the core values of society and embodied in the authentic and genuine experiences encapsulated by the corporeal and mythic spaces of Yellowstone National Park. Visitors to Yellowstone engage in a ritual experience which transports them from the ordinary to the extraordinary, where in their encounter with a genuine and authentic Other, they enter a liminal phase of transcendence and transformation. By constrasting I/Not I, both personal and national identities are formulated and reaffirmed. The return to the ordinary restores order from liminal inversion and validates the social norms of everyday life while providing an avenue for empowerment and the elevation of status. As visitor/photographer, the tourists become producers of cultural texts in the tangible form of photographic images, highly saturated with embedded symbolic meaning, and which reify and perpetuate the dominant cultural archetype(s). Every tourist snapshot taken while in Yellowstone National Park functions simultaneously at multiple meaning levels, including cultural production, personal artifact, family rite, souvenir, and a mechanism for the organization of memories. Embodying an intense commitment to appropriate an objectified desire, these images are re-creations of their own individual sight/site markers; the photograph as trophy and the photograph as witness are foregrounded. "Vanishing nature" was a recurring theme which surfaced in almost every interview. In this context, the photographs also function as statements of loss, and the photographic subjects as relics of the past. The overwhelming desire for an intimate and thereby authentic connection with a spectacular nature which was a primary motivator for the touristic venture, is compromised by the mediating presence of the camera. For many tourists, the primary desire for the experience itself becomes secondary to the importance of obtaining an image that freezes and captures the experience for organization in a paper museum of memories. Photographs and memories become conjoined as constructed autobiographies. On any given July day around the boardwalk just before an eruption of Old Faithful, thousands of strangers figuratively join hands and, in the liminal moment of Old Faithful's eruption, simultaneously imagine a shared community: Victor Turner's flow experience, communitas. For a brief moment, the cultural moment, this cross-section of humanity is of one mind, reveling in the exhilaration of the event

and the construction of a shared identity, including an American nationality. And in the superheated waters of Old Faithful, they find not only a window to the numinous Other, but also a mirror which reflects a validation and reification of the internalized myth complex they have each brought to the experience, of what they already know to be true. The authentic connection they seek is not only with the Sacred Other but, most significantly, also a verification of the Sacred Self. Furthermore, the photograph may be a miniaturization of the real and a manifestation of the consumptive structure of our culture, but for the Yellowstone tourists the act of making a photograph and the accompanying experiences are a celebratory rite as much as touristic ritual. These photographic trophies brought back from the liminal experience testify to the coalescence of the regenerative frontier myth with the ideology of vanishing nature. On many levels, the cultural purposes of Yellowstone and the photograph have changed little since the early days of each. Both function in a polysemic, multivocalic capacity to extol and institutionalize an invented tradition of idealized experience and beauty outside a ruined modern world.

Project title:	**Attitudes, Opinions, Characteristics, and Management Preferences of Backcountry Campers in Yellowstone National Park**
Principal investigator:	Tim Oosterhous
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Address:	4721 North University Dr. Apt. 603 Nacogdoches, TX 75961
Additional investigators:	Mike Legg, Ray Darville

Objective: 1) To gain an understanding of the socio-demographic and recreational behavioral characteristics of backcountry campers. 2) To ascertain how backcountry campers view the park's management policies. 3) To develop baseline data for future management decisions in Yellowstone and similar resource-based parks with substantial backcountry recreation components.

Findings: Results showed that typical backcountry campers in Yellowstone were young white males. The most distinguishing factor of these users was their high educational level; seventy-two percent had a college degree or higher. Some minor differences were detected between visitors and park employees in regards to management preferences. Overall, backcountry campers were very satisfied with their experiences in the park. Results indicate that users were pleased with the services received from park personnel when obtaining backcountry permits as well as the conditions they encountered in the backcountry. Some specific management conditions such as food poles at campsites and bridges over rivers that are dangerous to cross were highly desired. However, other conditions such as aircraft overflights and prohibiting wood fires were viewed as undesirable.

Project title:	**Integrating Ecology and Economics in the Greater Yellowstone Area: Valuation of Wildlife Core Attractions**

Principal investigator:	Dr. Jason Shogren
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Address:	Department of Economics & Finance Box 3985 University of Wyoming Laramie, WY 82071-3985
Additional investigators:	Todd Cherry

Objective: To measure the economic value of alternative wildlife experience in the park. Used a computer based survey to answer (No work was accomplished in the park, but rather just outside the boundaries).

Findings: Still collecting more survey data outside the park through a web-based interactive survey. Plan to have all data collected by April/May 2000.

VOLCANOLOGY

Project title:	**Eruption Observation of Selected Remote Geysers**
Principal investigator:	Jeff Cross
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Address:	915 E. Drake Rd. #213 Ft. Collins, CO 80525
Additional investigators:	Carlton Cross, Tara Cross

Objective: To obtain eruption interval and eruption duration measurements of selected remote geysers at Shoshone Geyser Basin (Double Geyser, Frill Spring); Gibbon Geyser Basin (Phoenix Geyser, Oblique Geyser); Heart Lake Geyser Basin (Glade Geyser, Rustic Geyser); and Lone Star Geyser Basin (Buried Geyser, unnamed geyser southwest of bridge).

Findings: Shoshone Geyser Basin: Double Geyser erupted every 3,349-4,209 seconds (mean of 39 intervals = 3,610 sec); Frill Spring erupted in series every 4.2-5.6 days (five intervals obtained), series lasting 7-11 hours and consisting of 34-43 individual eruptions at somewhat regular intervals. Gibbon Geyser Basin: Phoenix Geyser erupted every 5,817-8,179 seconds (mean of 140 intervals is 6,870 seconds. Heart Lake Geyser Basin: Glade Geyser erupted every 15,882-34,485 seconds (mean of 20 intervals = 24,985 seconds). Lone Star Geyser Basin: Buried Geyser erupted roughly every 9-11 minutes, long-term variations noted during July; unnamed geyser southwest of bridge erupted at irregular intervals of one to many hours.

Project title:	**Contemporary Surface Deformation of the Yellowstone Caldera**
Principal investigator:	Dr. Daniel Dzurisin
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Address:	U.S. Geological Survey Cascades Volcano Observatory 5400 MacArthur Blvd. Vancouver, WA 98661
Additional investigators:	Robert B. Smith, Wayne Thatcher

Objective: The fact that the Yellowstone caldera is deforming at geologically rapid and time-variable rates has been known for several decades, but the nature of the deformation source is still not well understood. This project aims to collect data on changes through time in the rate and pattern of surface deformation in order to further constrain models for the deformation source(s) beneath the caldera. These models, in turn, are being used to refine our assessments of volcanic and earthquake hazards within the park. Three different geodetic techniques are used: 1) precise leveling surveys along roadways every few years; 2) continuous Global Positioning System stations at several key sites; and 3) interferometric synthetic aperture radar (InSAR, a remote sensing technique) mapping each year when data are available.

Findings: We know from repeated leveling and GPS surveys that the surface of Yellowstone caldera has been deforming at rates of 1-3 cm/yr since the early part of the twentieth century. We also know that the deformation pattern changed from net uplift during 1923-1984, to steady subsidence during 1985-1995, and back to uplift starting in 1995. Various models indicate that the deformation source is located between 3 and 8 km beneath the surface. A satellite radar interferometry study published in 1999 revealed the presence of two deformation sources, apparently associated with two resurgent domes within the caldera. An important unresolved issue is the nature of the deformation source. Alternatives include pressure changes in the deep hydrothermal system beneath the caldera or movements of magma in the upper part of Yellowstone's active magmatic system.

Project title: **Measurement of Geothermal Water Temperatures at Hot River/Boiling River**

Principal investigator: Paul Miller
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Yellowstone NP, WY 82190

Objective: Monitor the temperature of the geothermal flow into the Gardner River at Boiling River.

Findings: Preliminary data only.

Project title: **Study and Monitoring of Selected Geyser Activity**

Principal investigator: Ralph Taylor
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West Chester, OH 45069-3611

Objective: Study the activity of selected geysers in the Upper Geyser Basin and West Thumb Geyser Basin to determine the activity patterns during the study period. This information will provide baseline activity data for these geysers.

Findings: In the summer of 1999, seven electronic recorders were maintained on the geysers that were monitored in 1997 and remained active. Data was recorded for all eruptions between July 7 and October 13 for all of the monitored geysers; in a few cases instrument failure caused loss of some data. The summary below shows the number of years of data that are available. The monitored geysers were: Geyser Hill: Aurum Geyser (3 years), Depression Geyser (3 years), Lion Geyser (2 years), Little Cub Geyser (2 years), Plate Geyser (2 years). Upper Geyser Basin: Pyramid Geyser (5 years). West Thumb Geyser Basin: Lone Pine Geyser (3 years).

Software was created to analyze the temperature records and detect all eruptions. For some geysers, duration is also detected; not all of these geysers have eruption characteristics that allow the duration to be determined from the temperature trace. The data collected spans an eruption of Giantess Geyser on August 23, 1999, and affords an opportunity to determine whether there is a connection between Giantess and the geysers being monitored. There is clear evidence of a connection between Giantess and Plate Geyser and Little Cub Geyser. The Plate Geyser connection was well known, but the Little Cub connection is less well documented. There is less definite evidence for an effect on Aurum, Depression, and Lion Geyser.

Other periodic or cyclic patterns in the eruptions are evident, and are strikingly different from those detected in 1998. Further analysis is required to determine what correlation may exist between the interval patterns of these geysers. Basic statistical and graphical analysis has been completed and the graphs have been made available to the park's interpretation division. Data from direct visual observation for many hours for the Geyser Hill geysers is also being analyzed. The intent is to create detailed descriptions of the activity of each of the monitored geysers in the final report. Pyramid Geyser continued to be a consistent feature with intervals around three hours. Lone Pine Geyser was less variable this year; in 1997 and 1998 there were numerous long (18-19 hour) intervals that punctuated the usual 16.5 hour intervals. In 1999, after a period of short (15 hour) intervals in June, the intervals stabilized at 16.5 hours and had only a few long intervals.

WATER QUALITY

Project title:	**Survey of High-Altitude Lake Chemistry in National Parks in the Western United States**
Principal investigator:	Dr. David Clow
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Additional investigators:	Rob Striegl, Dave Krabbenhoft, Jim Sickman, Don Campbell

Objective: The objective of this study was to conduct a survey of the chemistry of alpine/subalpine lakes in seven national parks in the western United States. The chemistry of these lakes will give an indication as to their sensitivity to perturbations such as acidic deposition and climate change. Results will be compared to a previous lake chemistry survey done in 1985 to see if there have been significant changes in water quality since the mid-1980s.

Findings: A chemical survey of 72 high-altitude lakes in seven national parks in the western United States was conducted during the fall of 1999. Lakes in the three California parks (Sequoia/Kings Canyon, Yosemite, and Lassen Volcanic) and in Rocky Mountain National Park (Colorado) were dilute; median specific conductances were less than 12 μS/cm and median alkalinities were less than 75 μeq/L. Specific conductances and alkalinities generally were substantially higher in Grand Teton and Yellowstone National Parks (Wyoming), and Glacier National Park (Montana), probably due to the prevalence of more reactive bedrock types. Concentrations of base cations and alkalinity were lowest in lakes in the alpine zone, probably because of minimal vegetation and soil development, and because of fast hydrologic flow rates. These conditions make alpine lakes highly sensitive to atmospheric deposition of pollutants.

Project title: **Reference Stream Monitoring - Long Term Trend Sites**

Principal investigator: Jim Eisenhauer
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Department of Environmental Quality
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Objective: The Department of Environmental Quality, Water Quality Division (DEQ/WQD), has been collecting long-term monitoring data for water quality, macroinvertebrate, and habitat at least impacted, reference stream sites in Yellowstone National Park. This data, along with other reference stream data collected throughout the state, will be used to help assess the quality of water at other sites that have been designated as impaired by the state of Wyoming. The state of Wyoming has been conducting its Beneficial Use Reconnaissance Program on streams that have been listed as impaired, but have been lacking in credible data to support the impairment. The water quality, macroinvertebrate, and habitat data that are collected at these sites will be compared to representative reference stream sites in the state to help judge the impairment.

Findings: Ongoing monitoring of long-term reference site, with no final report available at this time.

Project title: **Trophic Classification of Selected Lakes in Yellowstone National Park**

Principal investigator: Dr. Woodruff Miller
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Provo, UT 84602

Objective: Evaluate the trophic state of five lakes in the southern part of Yellowstone Park by analyzing nutrient concentrations and using traditional trophic models.

Findings: The purpose of this study is to evaluate the trophic state of five lakes in southern Yellowstone National Park in order to determine if the human activity in the local area is having a negative environmental impact and possibly increasing the eutrophication rate. While some previous analyses have been done on these lakes, this study is intended to be a preliminary trophic state evaluation to which future analyses can be compared. The five lakes sampled are Shoshone Lake, Lewis Lake, Heart Lake, Riddle Lake, and Duck Lake. Each lake, with the exceptions of Riddle Lake and Duck

Lake, was sampled at several locations. These samples were taken during the months of June through August of 1999 by Woodruff Miller and Dave Anderson of the BYU Civil & Environmental Engineering Department. The Carlson Trophic State Index, the Vollenweider Model, and the Larsen-Mercier Model were used to determine the trophic state of the lakes at each sampling location. The laboratory results were plotted on the applicable model. The Carlson Model requires measurements of the total phosphorus concentration, total chlorophyll-a concentration, and transparency. The Vollenweider Model requires the total inflowing phosphorus concentration and the hydraulic residence time. Finally, the Larsen-Mercier Model utilizes the mean inflowing phosphorus concentration and a phosphorus retention coefficient. As would be expected, the trophic state of the lakes varied from month to month. Generally, the lakes bordered between the oligotrophic and mesotrophic states. Shoshone Lake is classified as slightly oligotrophic, while Lewis Lake and Heart Lake are classified as slightly mesotrophic. Riddle Lake is classified as mesotrophic and Duck Lake borders on the slightly oligotrophic and slightly mesotrophic state classification. The results are summarized below.

Shoshone Lake Area:
DeLacy Creek (northeast side) - mesotrophic
Shoshone Creek (west side) - slightly oligotrophic
Near outlet (southeast side) - border of oligotrophic & mesotrophic
Shoshone Lake average - slightly oligotrophic
Lewis Lake Area:
Dogshead Creek (northeast side) - mesotrophic
Lewis River (middle north side) - slightly mesotrophic
Boat dock near outlet (south side) - border of oligotrophic & mesotrophic
Lewis Lake average - slightly mesotrophic
Heart Lake Area:
Witch Creek (northwest side) - slightly oligotrophic
Witch Creek (southwest side) - slightly mesotrophic
Heart Lake Average - slightly mesotrophic
Riddle Lake:
North side - mesotrophic
Duck Lake:
East side - border of oligotrophic & mesotrophic

Nitrogen was also measured in the samples so as to determine the nitrogen-phosphorus ratio (N:P ratio) in the lakes. This was done to determine if nitrogen or phosphorus was the limiting nutrient in algal growth. Every sample from all five lakes is phosphorus-limited except the August sample of Shoshone Lake at DeLacy Creek (northeast side) and the July sample of Lewis Lake at Lewis River (middle north side). This trophic state evaluation is meant to be a preliminary study to which future studies can be compared. Further sampling of the lakes and tributaries at different times and different locations will be necessary in the future. Complete 40-page reports of these trophic state classifications have been sent to the Yellowstone Center for Resources at Mammoth and to the Snake Ranger District at the South Entrance.

Project title:	**Missouri Madison Water Quality Monitoring Program**
Principal investigator:	Frank Pickett
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Objective: Objectives of the biomonitoring pilot study were to: 1) establish baseline conditions; 2) evaluate selected parameters, sampling locations, field and laboratory methods; and 3) evaluate the program's performance with regard to meeting long-term monitoring objectives.

Findings: Macroinvertebrates were collected using the modified kick-net procedure. The samples and data analysis were contracted to McGuire Consulting. The Madison River location in Yellowstone National Park had an increase of abundance of *Potamopyrgus antipodarum*. *Potamopyrgus*, an introduced snail first detected in the Madison River during 1994, accounted for slightly more than 60% of the benthic fauna in 1997 and 1998. Mayflies, stoneflies, and caddisflies are typically the most abundant macroinvertebrates in cobble-bottomed streams with good water quality. Mean values were much lower (less than 40%) at YNP. Lower and/or declining relative abundances of these groups are indicative of increased environmental stress. The YNP site supported a macroinvertebrate assemblage unlike those at any other station.

Project title:	**Yellowstone River Basin; National Water Quality Assessment**
Principal investigator:	Thomas Quinn
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Additional investigators:	David Peterson, Peter Wright, Gregory Boughton, Ronald Zelt

Objective: The overall goals of the NAWQA program are to 1) describe current water-quality conditions for a large part of the nation's freshwater streams and aquifers; 2) describe how water quality is changing over time; and 3) improve our understanding of the primary natural and human factors affecting water quality.

Findings: Samples of bed sediment and fish tissue have been analyzed for organochlorine compounds and trace elements. Interpretation is ongoing and a U.S. Geological Survey open-file report will be published in the year 2000.

Project title:	**Estimation of Soil Water Status in Yellowstone Grassland**
Principal investigator:	Dr. Jon Wraith
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Address:	Land Resources and Environmental Sciences Department Montana State University Bozeman, MT 59717
Additional investigators:	Rick Lawrence, Mari Henry

Objective: Much of the north-central United States, including the Greater Yellowstone region, is classified as semi-arid. Limited regional water storage capacity and groundwater supply coupled with highly variable annual precipitation make water the region's primary concern. During periods of prolonged drought, vegetation is subjected to water stress that affects the photosynthetic capacity of plant tissues and thus, the abundance and quality of available forage in grasslands (for example). Public and private land managers interested in rapid assessment of large areas for vegetative quality and quantity find that these are difficult to monitor because of natural variability and the large size of areas monitored. This research was directed towards providing quantitative estimates of available soil water status derived from combined remotely sensed and ground data. High resolution remotely sensed predictions of soil water availability across management regions would be useful for estimating the spatial extent of drought and to help quantify available forage. The work would be valuable to land resource managers, as well as having value to the global change research community by providing ground-truth measurements of soil and plant water status. In order to understand how soil water and vegetative water-deficit can be monitored remotely over large land areas, our research proposed to analyze the spectral responses of vegetation to physical changes in leaf structure and function across a natural gradient in soil water status. We hypothesized that: 1) plant responses to soil water gradients can be observed spectrally and can be correlated to soil water status; and that 2) soil water gradients would be evidenced by changes in leaf spectral responses such as chlorophyll content. In order to identify the spectral region(s) where leaf structure and function response to moisture can be detected, we proposed to relate hyper-spectral (many contiguous spectral bands) image responses to soil water status and leaf physiological responses.

Findings: On August 5 and 6, 1999, we had a small field crew in the Lamar River valley between the confluences of Cache and Soda Butte creeks during the scheduled time of the Probe-1 overflights. Multiple field measurements were collected across the several hectare area at the time of the hyperspectral overflight. Measurements included: 1) soil water content using time domain reflectometry (TDR); 2) a Minolta SPAD meter for measuring leaf chlorophyll content; and 3) a GPS unit for precise positioning of sample measurements. High resolution ($1m^2$) hyperspectral remote sensing imagery was collected from the Probe-1 sensor flown on a NASA-modified aircraft within Yellowstone National Park in the areas of Cache Creek, Soda Butte Creek, and parts of the Lamar River Valley as part of the extensive Yellowstone Ecosystem Studies EOCAP project. Unfortunately, failure of the on-board gyro-stabilized mount and GPS collection unit on the days we collected our field samples resulted in imagery that could not be geometrically corrected. Since positional accuracy was essential for locating our study plots, the hyperspectral data collected on these dates were insufficient. Subsequent flights later in

August and September failed to cover our research area and, as a result, useful hyperspectral measurements were not acquired for our analyses.

WILDLIFE MANAGEMENT

Project title: **Documenting Trends in Yellowstone's Beaver Population: A Comparison of Aerial and Ground Methods**

Principal investigator: Sue Consolo-Murphy
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Additional investigators: Douglas Smith

Objective: 1) To continue building a database on long-term beaver occupancy in Yellowstone National Park for trend monitoring of beaver activity and to estimate the density of colonies. 2) To compare the effort expended in time and funds with results achieved by both methods of survey. 3) To recommend a long-term strategy for monitoring beaver populations in YNP.

Findings: Ground surveys were completed between 8/23/99 and 11/20/99. Aerial surveys were completed late October 1999. Ground surveyors used a combination of evident feeding activity, animal observations, and construction on/around lodges and dens to judge active colonies. Aerial surveys relied upon the presence of a food cache, with or without a corresponding lodge/den, to determine active colonies.

Preliminary analysis indicates that ground surveys detected 68 active colonies, and aerial surveys detected 76 active colonies, 40 of which were independently detected by both methods. Survey routes were not completely similar. Aerial surveys detected some active colonies in sites not surveyed on the ground, while ground surveyors identified colonies not seen during aerial surveys. Detailed results and analyses will be presented in a formal report.

Project title: **Ecological Effects of Road Grooming on Bison in Yellowstone National Park**

Principal investigator: Dr. Robert Garrott
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Address: Fish & Wildlife Department
Montana State University
Bozeman, MT 59717

Additional investigators: Daniel Bjornlie

Objective: To describe the distribution, movement, and behavioral patterns of bison in the Madison-Gibbon-Firehole area of Yellowstone National Park with regard to the presence of groomed roads and to evaluate the ecological consequences of this management activity.

Findings: Mr. Bjornlie has finished his second and final field season of the study and is currently finishing data analysis. A thesis will be produced by the end of the spring semester 2000. Bison trail monitoring, quantification of bison groomed road use, behavioral observations, and distribution and activity surveys were conducted during both seasons. No correlation was found between bison road use and an index of snowpack (1997-98 r-sq = 0.17, p = 0.039; 1998-99 r-sq = 0.24, p = 0.046). The number of bison groups traveling on roads was relatively high in late fall prior to road grooming, decreased in early winter as road grooming began, and then increased slightly and leveled off in mid-winter. Road use then peaked sharply in late March and early April after road grooming had ceased. This sharp increase also coincided with the melting of snow cover in the lower-elevation meadows and south-facing slopes. Of bison groups observed traveling on roads during the road-grooming period, 60% (33 of 55) had negative reactions to interactions with visitors on oversnow vehicles. Only 18% of observed bison travel during the road grooming period took place on groomed roads. Most travel (57%) took place off roads and established trails. Bison appeared to utilize corridors such as waterways for off-road travel pathways. Data indicated that the Mary Mountain trail between the Hayden Valley and the Firehole continued to be the major route for bison winter distribution shifts. Bison moved to the Madison River and to Cougar Meadows as spring meltoff progressed. Bison displayed behavior that minimized the cost of traveling through snow. For December through March, travel accounted for only 0.7% of observed snow-displacing bison behavior, while foraging accounted for 42.5%. A detailed annual report was distributed to all cooperators in October 1998 and 1999.

Project title: **Winter Recreation Effects on Wildlife in Yellowstone National Park**

Principal investigator: Dr. Robert Garrott
Phone number: See previous entry

Additional investigators: Scott Creel, Amanda Hardy

Objective: To assess the effects of winter recreation on wildlife populations in the Madison, Gibbon, and Firehole drainages in Yellowstone National Park. Specifically, to estimate elk and bison distributions, abundance, behavior, and fecal stress hormone levels for possible spatial and temporal correlations to varying types and levels of human activity throughout the winter.

Findings: Currently in the second winter of field work, we are repeatedly and randomly locating 36 radio-collared cow elk, obtaining density, distribution, and behavioral data on the elk in the study area. We are conducting bison surveys throughout the study area every two weeks for bison density, distribution, and behavioral data. We are collecting fecal and urine samples from radio-collared elk, unknown elk, and unknown bison for analysis of glucocorticoid levels (as a stress hormone indicator) and allantoin:creatinine ratios (as a nutritional deprivation indicator). We are conducting road, trail, and off-trail surveys throughout the study area, documenting elk, bison, coyote, deer, moose, trumpeter swan, and bald eagle sightings, along with group size, distance from road or trail, behavioral responses to human activity, and types of human activities and behaviors present. All data are being collected to detect possible spatial and temporal variation related to winter recreation activities and levels or other confounding variables such as winter severity or nutritional stress. We are processing the fecal samples from the 1998-1999 field season and are beginning analysis of the 1998-1999 data.

Project title: **Predator-Prey Dynamics in a Wolf-Ungulate System**

Principal investigator: Dr. Robert Garrott
Phone number: See previous entry

Additional investigators: Rose Jaffe, Lee Eberhardt, Doug Smith, Kerry Murphy

Objective: To examine the prey selection of wolves on the ungulate populations in the Madison, Firehole, and Gibbon drainages of Yellowstone National Park. Specifically, studying predation rates, prey selection, and wolf movements according to landscape attributes and prey abundance and distribution patterns. Aspects of prey selection being studied include species, sex and age class, condition of prey, and landscape features and snow conditions of encounter and kill sites. The data collected will be used to help predict impacts of wolf predation on the prey populations.

Findings: Data were collected from November 1998 to May 1999. Travel routes and locations of hunts and kills were recorded through the daily ground tracking of wolves in the study area to determine wolf

movements in relation to landscape features and prey distribution and abundance. Necropsies were performed on wolf kills to ascertain the species, age, sex, and condition of the prey to study prey vulnerability and wolf prey selection. Detailed snow condition data were also collected by digging snow pits and recording snow layer information, and sinking depths of wolves and elk were taken at hunt and kill sites to examine the possible effects of snow conditions on prey vulnerability. All bison calf kills were located on snow-free thermals, so no snow condition data were recorded. The amount of data collected was determined by daily wolf activity.

The Nez Perce pack, with four adults and three pups, were detected in the Firehole Drainage 136 days, establishing the area as an important part of their winter territory. The Chief Joseph pack moved through the study area twice for three days with six wolves in December and five wolves in February. Tracks of one to two uncollared wolves were detected in the study area on two occasions. The ungulate prey base in the study area consisted of approximately 900 bison and 650 elk throughout the winter. Fifty definite and 11 probable wolf kills were located and necropsied, including 31 elk calves, 11 cow elk, 8 bull elk, 2 unknown adult elk, and 9 bison calves. Prey switching was evident; elk calf kills were located from November through March, increasing steadily from November to February and decreasing in March, adult elk kills were located throughout the winter with an increase in spring, and one bison calf kill was located each in December and February, increasing in March and April. Of the 173 days the wolves were monitored, radio signals were detected 136 days and followed 97 days. Wolf tracks were located and followed, and travel routes recorded 79 days for a total of 307 km.

Project title:	**Determining Forage Availability and Forage Use Patterns in the Hayden Valley**
Principal investigator:	Dr. Lynn Irby
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Address:	Biology Department Montana State University Bozeman, MT 59717
Additional investigators:	Peter Gogan, Thomas Olenicki, Robert Garrott

Objective: 1) Delineate seasonal forage use patterns by bison in the Hayden Valley. 2) Determine long-term and short-term effects of ungulate foraging on vegetation in the Hayden Valley. 3) Identify cost-effective monitoring strategies for monitoring impacts of ungulates on vegetation. 4) Estimate annual production and standing crop available to ungulates in the Hayden Valley.

Findings: We initiated fieldwork in June 1998. During the 1999 field season we monitored standing biomass via grazing exclosures at three fixed sites and 70 randomly selected plots. Biomass was estimated using either clipping or multispectral radiometry calibrated via clipping. We were also able to complete ground calibration for three LANDSAT overpasses and do offtake estimates in two blocks in

the Hayden Valley using a combination of the grazed loop technique and multispectral radiometry. Fine and medium scale criteria for bison selection of foraging sites will be facilitated by aerial and radio-telemetry locations (medium scale) and locations of bison using a laser range-finder (fine scale) The project is proceeding on schedule.

Project title: **Impacts of Roads on Movements and Habitat Use by Bighorn Sheep on the Northern Range**

Principal investigator: Dr. Lynn Irby
Phone number: See previous entry

Additional investigators: John Mack, Kayhan Ostovar

Objective: 1) To identify movement patterns, seasonal ranges, and relationships among bighorn groups on the Northern Range. 2) To determine how current roads impact movement and behavior. 3) To identify areas that would be sensitive to new road construction.

Findings: Mr. Ostovar completed his thesis in December 1998 to complete the movement and road impact portion of the study. During winter 1999, I monitored survival of sheep from ground locations. All sheep with radios survived through April 1999. During summer 1999, I conducted a road shoulder survey to determine the relative suitability of road margins as escape blockages and foraging sites for sheep. Areas used by sheep were in steeper terrain than areas not used by sheep but roadside vegetation was not different. Very few road margins precluded sheep movement off of roads. Two papers based on Mr. Ostovar's thesis have been written and will be submitted to professional journals in 2000. Museum specimens we collected are limited to DNA archival specimens from captured animals. They are stored with other DNA material at Mammoth.

Project title: **Epidemiology and Pathogenesis of Brucellosis in Yellowstone National Park Bison**

Principal investigator: Dr. Thomas Roffe
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Bozeman, MT 59717-0322

Additional investigators: Jack Rhyan, Keith Aune

Objective: Determine the natural course of brucellosis in free-ranging bison. Determine modes of transmission. Provide information on the prevalence of infection and abortion.

Findings: We currently have 55 collared bison entering the fifth year of this project. Our focus will be on younger female bison coming into their first reproductive years. Based on data we have collected to date, bison apparently develop clinical brucellosis during their first pregnancy after exposure to the bacteria. Repeat reproductive failures, induced by brucellosis, appear to be uncommon. We also plan to focus on vertical transmission from cow to calf. Last spring we reported eight neonatal mortalities during the 1999 calving season. Three of these dead neonates were brucella-culture positive.

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